

AFIT/GSM/LAC/97J-1

THE HIGHLY-AUTOMATED AIRPLANE: ITS
IMPACT ON AVIATION SAFETY AND AN
ANALYSIS OF TRAINING PHILOSOPHY

THESIS

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AFIT/GSM/LAC/97J-1

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THESIS

Presented to the Faculty of the Graduate School of Logistics
and Acquisition Management of the Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Systems Management

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June 1997

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Acknowledgments

I would first like to thank my advisor, Dr. David K. Vaughan, a former C-130 pilot and retired U.S. Air Force Academy instructor, who now serves as Assistant Dean for Research and Consulting at AFIT, for his guidance and patience in helping me complete this thesis. His direction has helped me from nothing to everything. Without his counsel and kindly advice, this thesis could not have been completed.

Also, I would like to thank my family for supporting me to complete my work with great love and best wishes. I will always remember my father who put all of his faith in me in his life, my hard working mother, my loyal wife and my lovely daughter. They all deserve the best thanks from my heart.

Kuo Kuang Liu

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Abstract

Two Airbus accidents at Nagoya, Japan and Toulouse, France in April and June 1994 highlighted the problem of the highly-automated airplane and its interface with pilots. As technologies in the engineering design progress so quickly in airplane automation, training philosophies toward the "glass cockpit" may need to be re-evaluated. Many pilots, young and old, praise the advantages brought by the new technology. On the other hand, many have complained about the increasing workload and the danger of automation features which are not in their control.

In this thesis, I evaluate the accidents of the highly-automated airplane and the probable solutions which can be applied in the training phase to reduce the accident rates. The training philosophies given to the crewmembers remaining in the cockpit of highly-automated airplanes should guarantee flying safety with limited time and resources in the absence of rigorous regulations. Air transportation surely is the most popular business today and in the future. The machine has been updated to include more automatic controls. Now our concern is to upgrade the human capability to stay abreast of technology and keep flying safe. That is the reason for this thesis, whose contribution to aviation safety is to recommend adequate training philosophies for highly-automated airplane users.

The findings of this thesis suggest that in the highly-automated cockpit era, basic flying skill training, operating skill-based FMS training, and functional knowledge-based

FMS training are all important during the training phase due to the unique features of the highly-automated cockpit.

Pilots need basic flying skills to maintain minimum safety when loss of automation occurs or when an unusual situation forces them to turn off the automation and fly the aircraft manually. Pilots also need operating skills to operate the Flight Management Systems quickly, correctly, and efficiently. Most importantly, pilots need the knowledge of the functional theories of Flight Management Systems. When pilots thoroughly understand the design and function theories of automation systems, they will easily be able to recover from automation failure, and will be more willing to take over in case of malfunctions of automation systems.

HIGHLY AUTOMATED AIRPLANE: ITS IMPACT ON AVIATION SAFETY AND AN ANALYSIS OF TRAINING PHILOSOPHY

I. Background

In April 26, 1994, I was working in the Chung Cheng Institute of Technology as an aviation safety officer, managing the safety course and teaching. Late at night, television broadcast the news that a China Airline A300-600R crashed at Nagoya International Airport, Japan. All but eight of the 271 passengers and crew died. Everyone on our staff was shocked. We were eager to find out the cause of that accident. While that case was still under investigation, on June 30 of the same year, another Airbus A330 crashed in Toulouse, France. This time, the fatality list included an Airbus Industry chief test pilot, a flight test engineer, an A320 instructor, an operations/training group manager, a market analysis manager, and two MD-80 captains.

Normally, the cause of an accident comes from one of three categories: man, machine, or media (the flying environment and management). In these instances, the problem probably did not result from a lack of flying skill. The CAL A300 pilots were both fully qualified. The French A330 pilots were not only qualified, but also had expertise with the Airbus. But why did those experts fail to control the Airbus? In those two cases, all the pilots were fully qualified. Both Nagoya and Toulouse reported good weather conditions and no other traffic was in the area when these accidents happened. Both the A-300 and A-

330 systems actually functioned well. All their systems did exactly what that were designed to do. Then what caused the accidents to happen? Both investigation reports showed that the airline pilots were shocked at the moment of the accident when the Airbus did what it was designed to do instead of what the pilots wanted it to do. After the accidents, experienced A-300 pilots indicated that the CAL crew might have saved the aircraft had they reverted to basic flight procedures (Mecham, 1994:32). The A-330 investigation team suggested additional development work to enhance flight envelope protection when selecting the autopilot's altitude acquisition mode, and it suggested a preparatory briefing for the crew members should precede the flight (Sparaco, 1994:20).

In these two cases, some integration problems clearly existed between man and the highly-automated machine. The investigation data showed that at the moment when the accidents happened, the pilots were not in control. The automatic flight management systems (FMS) were actually overriding the human command. The cockpit voice recorders of the CAL and the A330 recorded the struggle between the pilots and the automation command when these accidents happened (see Appendices B and C for detailed cockpit conversation between the pilots).

Introduction

Throughout history, people have been interested in flight. But, we do not have the ability to fly like birds. Flight has always depended on our ability to build machines to carry us up. The history of flight is really a history of mankind's ability to invent and

perfect the man in those machines (Bacon,1983). One problem encountered before was desire vs ability. As has been said before, "The requirement pushes and technology pulls." However, today the situation has changed dramatically. The airplanes are so advanced that they are able to override the human capability. To know how to make the systems work for a pilot has become today's biggest cockpit issue. Workload in the past was measured mainly in physical terms, for example manually controlling the stick, manually calculating the navigation variances, and reading the penetration chart to review a landing pattern.

Today, a modern airplane includes those functions which are so versatile that no more than two crewmembers (Captain, First Officer) are needed to perform tasks which used to require five crewmembers (captain, first officer, flight engineer, navigator, and radio officer). The rapid introduction of advanced computer-based technology on the flight deck has dramatically changed both the aircraft operation concepts and the role of the flight crew. Modern cockpit technology has shifted the tasks of pilots from physically flying the aircraft to managing it (Hughes, 1992a:50); thus, the pilots' role appears to have changed from airplane controllers to system managers. However, to achieve the efficiency of automated flight, vast amounts of flight plan data must be stored in computer memory. Unfortunately, the human brain's capability to absorb and digest data and make critical decisions based upon all the data has not changed. The mental workload that an individual has to completely master about every system operating in that airplane could be more demanding than the physical workload on a traditional airplane.

People agree that automated devices can provide more efficient and precise flight operations, but automation also requires extra skills to monitor and properly set these devices. In those areas, people can and do make errors (Wiener, 1987:162-181). The pilots' knowledge of managing the computer systems and correctly reacting to the abnormal situations when computers go wrong becomes critical. To manage the on-board computer systems requires good operating skills. However, to correctly react to abnormal situations, pilots need to possess not only good operating skills, but also thorough knowledge of the operating theory of the systems.

Problem Statement

As new technologies are continually introduced into the modern cockpit, aircraft design has been moving toward more automatic functions for improving performance and efficiency, lowering pilot workload, and reducing or eliminating human error. Those automation features sometimes appear as impersonal, generalized, and group-oriented to pilots (Demosthenes, and Oliver, 1991:22). During the transition training phase, the kind and amount of training a pilot receives in the automated cockpit environment will determine how confident that pilot's attitude is toward automation. Accordingly, pilot performance with automation can vary significantly among individuals and even for the same individual over time.

A highly-automated airplane can be flown in three ways: fully automated, using the

flight management computer; on basic autopilot, using altitude and heading hold; or manually (Hughes,1992:50). The airlines choose the first of these options because the fully-automated airplane enhances economy, efficiency, and safety. The flying public also prefers this option because the fully automated airplane has increased speed, altitude consistency, and flight comfort.

Flight Management Systems onboard the highly-automated airplane today can fly the aircraft from just after takeoff until touchdown, making precise speed and altitude adjustments en route (Nordwall,1995:48). This feature has changed the pilot's role to a systems monitor instead of a hands-on operator (Hughes,1992:50). A proficient pilot's ability to control and monitor the FMS system determines how safely and efficiently the pilot will operate the highly-automated airplane. In most major airlines, the FMS-based automation training has become the principle issue of pilot transition training.

Airlines which use the highly-automated airplane for transportation operations normally train their pilots in two phases. The first phase is the basic flying skills training phase. In this phase, student pilots receive their airline pilot rating through many channels and methods (details addressed in Chapter 2). The basic flying skill training phase is completed before the company sends its pilots to duty. The second phase, called the advanced phase, is a transition training phase. In this phase, student pilots train on the traditional airplane, which has few or no automation features, and the highly-automated airplane, with high degrees of automation features in the cockpit. As these pilots are already qualified in basic flying skills, the training focus in this transition phase is on how

to use those on-board automation systems to effectively fly the airplane. In this phase many questions about the effectiveness of current training theory in the highly-automated era have been asked and attention must be paid to them. Which training philosophy is best to deal with the automation features in cockpits has become an important issue because its results relate deeply to flying safety.

The advanced training phase (transition from the traditional airplane to the highly automated airplane) mainly deals with the sophisticated automation system called the Flight Management System (for a detailed explanation of the FMS systems, see the next chapter). The Flight Management Systems (FMS), like all other systems, has two parts to be learned: the theory of how it functions, and its operation.

However, because the training of the FMS system is mainly conducted during the transition phase, pilots, with time pressures and limited resources (instructors, facilities, machines), have argued about which one is more important, the skill (how to use it) or the knowledge (to know why the system works a certain way). Some pilots pay attention to learning how to operate the keyboard, while others pay attention to understanding how the systems work.

Research Question

New technologies have led the aerospace industry into the automation era. Those new technologies provide pilots with many options in flight. As expected, the highly-automated airplane with its unique features can benefit flying safety and the economy; however, many new types of accidents also emerged due to unique automation problems which acted in

opposition to the creators' original safety concerns. In reviewing accidents/incidents related to the automation system problems, it is apparent that some pilots solved their on-board problems before a crash occurred, while some pilots failed to deal with them, resulting in tragic fatal accidents. Pilots' capabilities and attitudes toward the automation systems varied depending on the degree of automation training the pilot had received. However, with limited training resources and considering the unique automation features of the highly-automated airplane, which training is more important? Is flying skills training, Flight Management Systems-based operating skills training, or Flight Management Systems-based function knowledge training more important? Is there an appropriate balance between skill-based and knowledge-based training philosophies?

Investigative Questions

To answer the research question, these investigative questions will be answered in turn.

1. What is the new automation's impact on aviation safety? Is cockpit automation increasing aviation safety or bringing more problems to aviation? As many accidents have happened in the decades since these automation features began to be employed, what problems can we determine to be associated with automation?
2. Before the introduction of automation into the airplane, the pilot had to fly the aircraft manually. Without the automation feature's aid, flying skill was the only pilot-related concern to the aviation safety. However, since the introduction of the automation features into the cockpit, many flying skills have been replaced by the Flight Management Systems. New training approaches are now needed to cope with the automation features. What is the

traditional training approach? What are the differences between the traditional and the new training approach?

3. To deal with the automation features, some people think operating skill is more important because it is basic to be able to smoothly command the airplane. However, other people conceive that understanding the function of automation features is more important. With limited resources and vague regulations, we need to find out what is the best balance between those two training approaches to improve flying safety. What is the best balance of skill-based and knowledge-based training to deal with new technology?

Methodology

This thesis, which attempts to determine an appropriate balance among the training philosophies of basic flying skill-based training, operation skill-based FMS training, and functional knowledge-based FMS training in the highly-automated cockpit, employs the method of comparative case analysis. According to Cooper and Emory, case analysis is able to examine a variety of contextual events which bear upon the primary investigative area (1995, 116). Cooper and Emory state that the case analysis approach provides an emphasis on detail that gives "valuable insight for problem solving, evaluation, and strategy" (1995, 117). In this study, case study examination of a variety of highly-automated airplane accidents provides the details necessary to analyze the new type of accidents resulting from highly-automated airplane. Details linked to pilot performance in these accidents point to a need to explore issues and aspects associated with aircrew training

philosophies, in particular between skill-based and knowledge-based training. The case analysis approach used in this study links these accidents with information provided in a recent Embry-Riddle study.

A study conducted by Embry-Riddle Aeronautical University in 1993 analyzed comments from 4,100 pilots who regularly flew corporate missions. That survey identified pilots' attitude towards and comments about cockpit automation. From those problems commented on by active pilots in the Embry-Riddle Aeronautical University study and problems of automation defined by the Air Transport Association of America in 1989, two case analysis matrices were designed to compare the responses. Finally, examination of two actual accidents of Airbus aircraft which took place in 1994 were used to evaluate the information derived from those two evaluation matrices.

Conclusion

Recent accidents caused by cockpit automation features have brought about new concerns. Technology has successfully improved the flying character of the airplane. However, to cope with those new technologies, training philosophies need to be re-examined.

Chapter Two examines the difference between old generation airplanes and new generation airplanes. The motivation for automation and the advantages/disadvantages of automation are explained to introduce the problem areas of automation features in modern cockpit. It is important to identify those problems to provide proper approaches to solving

them.

Chapter Three explores the different philosophies of training. The focus is on Flight Management Systems training, the new training philosophy dealing with automation features. The chapter also compares legal requirements and the problem of inefficiencies of those requirements associated with the automated airplane's training needs.

Chapter Four identifies the distinctions between Operating Skill-Based FMS training and Function Knowledge-Based FMS training to find out which one is more important according to flying safety principles.

Chapter Five identifies the missing part of the current training philosophy. Finally, some suggestions will be provided to improve aviation safety in the highly-automated airplane era.

II. The New Generation Airplane and Its New Generation Accident Style

Earl Wiener identified several reasons for automation such as 1) availability of technology, 2) safety, 3) economy, reliability, and maintainability, 4) workload reduction, and 5) more precise flight maneuvers and navigation which promoted the application of automation into the cockpit (Wiener, 1988:444). However, in the aerospace industry, every time a problem is solved by technology, a new one may be created (Wiener, 1988:439).

The Highly-Automated Airplane

The highly-automated airplane is an airplane with advanced high technology automation systems onboard the aircraft that enable the aircraft to utilize automatic controlling features. Typically there is a Flight Management System (FMS) which includes Flight Management Computers, electric displays, advanced capability autopilot/flight director systems and centralized crew alerting systems (Ekstrand, 1990:7) and an Electronic Flight Instrument System (EFIS). These features are possibly supplemented by additional automated features such as fly-by-wire, autothrottles, engine indicating and crew alerting systems, and a collision avoidance system (Norman and Orlady, 1988). Also, the cathode ray tube is widely used in the cockpit, engendering the term "glass cockpit." In the highly-automated airplane, computer has taken over much of the pilot's work. The process of flying the airplane has become the computer flies the plane and pilot flies the computer.

In this thesis, the highly-automated airplane is defined as “those airplanes controlled by computer programmed systems such as EFIS and FMS.” The examples are MD-80s, 737-300/400s, 757s, 767s, BAE 146s, A-300s, B-747s.

The Old Generation Airplane

The old generation airplane is the traditional airplane, defined as “those airplanes which are controlled by cable and with very few or no computer assistance in flight control, navigation, or information display.” On early aircraft the commands of the pilot were transmitted to the control surfaces mechanically via cables. On heavier aircraft these signals were transmitted electrically and caused hydraulic actuators to move (Faith:1996). Examples of these aircraft include Comet IVs, 707s, and DC-8s in the late 1950s and 727s, 737-100/200s, and DC-9s in 1960s.

The Purpose and Background of Automation

Historically, aircraft design has moved toward more automation with the goals of improving performance and efficiency, lowering the pilot’s workload, and reducing or eliminating human errors (Demosthenes, and Oliver, 1991:22). Before we have an in-depth evaluation of the advantages and disadvantages of automation, it is important to understand why the aerospace industries would seek automation.

The Motivation for Automation

During the 1970s and 1980s, to meet the need of reducing the pilot workload and the demanding task of all-weather operations, the concept of automating the aircraft as much as possible was then considered appropriate. Researchers at Embry-Riddle University indicated that the reasons for automation are: 1) to provide the aviation industry with the opportunity for a safer and more efficient means of transportation; 2) to achieve higher productivity by reducing both the human workload and the workload through automation of routine tasks; and 3) more economical functions (Wise, 1993a:8). Earl Wiener defined the reasons above as 1) availability of technology, 2) safety, 3) economy, reliability, and maintenance, 4) workload reduction, 5) more precise flight maneuvers and navigation (Wiener, 1988:444).

The earliest automation dates back to 1924 in France. The automatic system enabled the airplane to maintain a horizontal flight path and fly to a preset destination. It used the gyroscope to keep the aircraft on an even keel (Pyle, et.al., 1992:213). On 10 June 1965, the world's first commercial service automatic landing was utilized by BEA pilots at Heathrow airport, London (Pyle, et.al., 1992:635).

Today, technologies have been greatly improved and new types of sophisticated and complex commercial aircraft to help pilots have been generated, including the Cathode Ray Tube (CRT), Automatic Throttles, Fully Automatic Landing Systems, Fly-By-Wire system, and the Flight Management Systems. In flight, those systems will accept air data and navigation inputs to correct and refine the required program and provide a series of inputs

to the automatic flight system which precisely guides the airplane (Beaver, 1989: 128). These features all improved the efficiency of flight. Current trends in cockpit technology are toward more automation, driven by the ability to use two-pilot cockpits to save airlines the cost of the third crewmember. More information is available for pilots, and the new technology provides quick, automatic reaction, within safe aircraft limits, and increased equipment reliability and maintainability (Andelin and others, 1988:165).

The Flight Management System (FMS)

The Flight Management System consists of many units. Different aircraft have different features. However, the FMS systems generally include the combination of Automatic Flight Control System (AFCS), Center of Gravity Control Computer (CGCC), Flight Augmentation Computer (FAC), Autopilot/Flight Director System, and Autothrottle System. Chet Ekstrand, Flight Crew Operations of the Boeing Commercial Airplane Group, stated:

The last decade has seen the introduction of many high-technology airplanes into the air transportation system. These high-tech airplanes have typically brought us flight decks with a highly integrated Flight Management System (FMS) which, among other elements, includes Flight Management Computers (FMC's), electronic displays, advanced capability autopilot/flight director systems and centralized crew alerting systems. (Ekstrand, 1990:7)

The Character of a Highly-Automated Airplane

According to those function features described above, today the computers can take

over all aspects of flight management. C.K. Manning, a retired Royal Navy lieutenant commander, described the highly automated character as follows: "Take off is still a manual maneuver, but the autopilot goes in soon after, and crews need only touch buttons for the next 10 hours to complete a perfect flight and automatic landing" (Manning,1984).

Since highly-automated airplanes largely use computers to control a flight mission, many duties are done by the machine instead of humans, such as warning systems, control systems, navigation systems, artificial intelligence, and so on. These technologies attempt to use computers to solve problems in a manner that simulates the human reasoning process, in other words, to think for the pilots. They help the pilot to make decisions by using a human's logical approach to thinking based on expert experience design. Highly-automated systems reduce the flying workload of the pilots and channel information to them. For example, the automation in the A-300 has the functions of altitude and heading hold, high/low speed protection, auto-throttle. Those systems remove much of the workload from the pilot, allowing him to concentrate on other duties. These systems channel information to the pilot, like the "glass" cockpit, which presents data to the pilot using cathode ray tubes, or TV screens, instead of traditional instruments.

The Highly-Automated Airplane: The A320

Among all different degrees of automation, the Airbus series is no doubt one of the highest. The A320 was introduced by the Franco-German-British-Spanish Airbus consortium in 1988. Its electronic centralized aircraft monitor (ECAM) on board is an

example of pilot/vehicle integration. The ECAM uses one of the central cathode ray tubes, and through automatic or manual selection, presents pictorial drawings of all important aircraft systems of the A320. The electrical drawings will show the status of the aircraft busses, voltages, currents, plus any problems that are occurring. Using the ECAM, the flight crew can quickly and accurately determine exactly what the status of a particular aircraft system is. After engine start, the ECAM presents the checklists automatically as they are required.

When loaded the standard instrument departure (SID) into the flight management computer system (FMCS), the massive on-board computational power will ensure precise flightpath holding, the responsibility of the electronic systems. The computers are programmed with all of the relevant aerodynamic data such as speeds and attitudes to control whatever the pilot may try to do. The computers always try to prevent inadvertent overspeeding, stalling or overstressing the airframe.

Its basic digital aircraft flight control system is comprised of a single flight control computer (FCC) for flight director and autopilot functions, a thrust control computer (TCC) for speed and thrust control, and two flight augmentation computers (FACs) to provide yaw damping, electric pitch trim, and flight envelope monitoring and protection. With all of those automation features on board, the A320 is a paradigm of the highly-automated airplane (Steenblik:1987,20).

The New Generation Accident Style

The new generation accident style differs from the old one in that those accidents are caused by the automated flying systems. Their characteristics can be described as silent, surprising, and unpredictable (Wise, et.al.:1993). Following are two typical examples:

In 1979, a DC-10 crashed into Mount Erebus in Antarctica killing 257 persons. The route change was selected by the airline dispatcher for this sight-seeing flight and the coordinates of the waypoints were incorrectly computed. When the flight crew input this data into the aircraft INS (inertial navigation system), the error of the waypoints was equivalent to 26 nautical miles off course. This resulted in a programmed flight directly into mount Erebus, not safely down McMurdo Sound as was intended. This route change, combined with the fact that the crew totally accepted the new flight plan without careful review because of their blind reliance on the automated systems, contributed to the aircraft's crashing into the mountain side (Wiener,1987:162-181).

Another case involved the downing of Korean Airlines Flight 007 in 1983, a B-747 with 269 passengers on board. The crew violated Soviet airspace for unknown reasons and was shot down by Soviet fighters. Several explanations have been presented to explain why the airliner was so far off course (Pyle, et. al.,1992:794). Wiener has suggested that it may have simply been a matter of digit inversion in the navigation flight computer system that resulted in a 300 mile course deviation (Wiener,1987b:162-181).

In these two cases, pilots did not know they had made the mistake until the accidents happened, illustrating the characteristics of silence, surprise, and unpredictability. Aviation

Week & Space Technology has listed 10 accidents caused by high-automation problems (see Appendix D). Research conducted by the FAA's human factors team in 1996 listed 24 automation-related accidents/incidents (see Appendix E).

In those accident records, pilots were dependent on the automation to control the airplanes. As Captain Heino Caesar of Lufthansa said, "For the first time in aviation history, pilots no longer had undisputed and direct access to the flight controls of the aircraft but were dependent on what the construction engineers programmed into the software" (Faith:1996). However, when computers went wrong, or when pilots input erroneous data, or when pilots did not understand the automation functions, these problems could result in an accident. Pilots were surprised at the time the accidents happened because the events were not expected, were silent, and were unpredictable. Those accident causes were not what the pilots planned or intended to do, but their mistaken input error or misunderstanding of the automation function led to the accidents. Other accidents were caused by the erroneous keyboard entry of data into flight management computer systems and other keyboard-based devices on the flightdeck, such as the Air New Zealand and KAL cases (Lofaro:1991:880).

The Accident Style of Old Generation Airplane

The first powered aircraft was successfully flown by Orville Wright at Kitty Hawk, North Carolina, on December 17, 1903, and the first old generation airplane accident happened at Fort Myer, Virginia on September 17, 1908. The first victims were Orville

Wright and Lt. Thomas Selfridge of US Army. The cause of this accident was suspected as an overstress of the airplane's control limits (Pyle,et.al.:1992). Up to the 1980s, when automation command was introduced into the cockpit, most of the accident features were skill insufficiency-based, like the stall, spin, midair collision, and overshooting the runway. In the old generation airplane, because the pilots were actually in command, when an accident happened, pilots knew it was going to happen, or at least knew what happened to cause the problem.

Today, many of the old generation airplanes are still in service in many areas, and the old generation style accidents still happen frequently. However, before this problem was solved, a new concern emerged. This new concern is the highly-automated aircraft and its impact on flying safety.

Comparing those two different accident styles, along with the previously discussed research findings that modern cockpit technology has shifted the tasks of pilots from physically flying the aircraft to managing it, we can conclude that for different generation airplanes with different operating theories, different training philosophies should be addressed.

The Advantages and Disadvantages of the Highly-Automated Airplane

The use of automation and technology in flight improves efficiency and precision. It has improved performance and efficiency, lowered pilot workload, and reduced human error. However, the aviation system has become much more impersonal, generalized, and group-oriented (Demosthenes and Oliver,1991:23). Many pilots are quoted as saying that

while they enjoyed flying highly-automated airplanes, they had strong doubts about safety and workload reduction (see Appendix F). Their reservations about safety were based on a fear that pilots tended to lose situational awareness in the automated cockpit and that merely monitoring the new instrumentation would lead to complacency (Glines,1990:21). With decreased manual control and increased monitoring, pilots would become quite bored during cruise flight. This can lead to two insidious and dangerous results: taking more time to detect failures, and becoming less accurate in diagnosing these failures (Patrick,1996:19). During departures and arrivals, the disadvantage is that the workload becomes excessive with the slightest change to the flight plan. Pilots occasionally fail to respond appropriately to an emergency. Easily-made mistakes, like forgetting to enter north or south latitude into the GPS, or setting the wrong three-letter identifier into the LORAN, can result in a significant off-track deviation (Patrick, 1996:18), another disadvantage that is difficult for pilots to detect during flight.

Embry-Riddle Aeronautical University has conducted research of automation and its influence on human factor issues (Wise, et.al.,1993). In that research, it listed the advantages and disadvantages originally published by Wiener and Curry in 1980 (as in Table 1). It briefly introduced the category of the highly-automated airplane and its pros and cons to the aircrew (Wiener and Curry,1980).

That table shows that the new-generation airplane has benefited the pilot and has caused new problems. New training is needed to reduce the disadvantages of the new-generation airplane. Before we discuss the new training needs, we have first to analyze how

automation assists or hinders pilot performance.

Table 1. Advantages and Disadvantages of the Highly-Automated Airplane (Wiener and Curry,1980)

Advantages	Disadvantages
Increased capacity and productivity	Seen as dehumanizing; lower job satisfaction; consumer resistance
Reduction of manual workload and fatigue	Low alertness of human operators
Relief from routine operations	Systems are fault intolerant - may lead to large errors
Relief from small errors	Silent failures
More precise handling of routine operations	Lower proficiency of operators in case of need for manual takeover
Economical utilization of machines (e.g., energy management)	Over-reliance; complacency; willingness to uncritically accept results
Damping of individual difference (narrower tolerances)	False alarms
	Automation-induced failures
	Increase in mental workload

Advantages of Automation

There are several areas in which automatic control helps pilots:

1. The Multi Function Display (MFD). During radar vectoring for approaches, pilots can see (pictorially) their position and this helps pilots to know their accurate location at all times. This enhances the orientation, reduces workloads, and provides safer operation. In heavy traffic areas like New York, automatic depiction of holding patterns helps pilots to control the airplane when a sudden route change is given by Air Traffic Control. The checklist on the MFD helps prevent pilots from skipping any items when contacting ATC and helps them to be able to look for traffic in the terminal areas and maintain situational awareness. These features show the advantages of increased capacity and reduction of

workloads during flight by automation.

2. Autocommands. The autothrottles bring many benefits to pilots. In heavy weather and strong cross wind situations, the autothrottle's go around and automatic selection of altitude saves pilots workload so pilots can spend more time on monitoring the instrument panel. These features also show the advantages of increased pilot capacity, reduced workload, and relief from routine operations by the assistance of automation.

3. Decreases Workload Enroute. When the system is programmed properly and accurately in the first place, workload is decreased markedly during flight. But the premier aspects here are 1) flight factors are known, 2) ATC allows the whole flight plan as requested, and 3) everything goes as planned. Pilots then do not have to worry about workloads on power setting, calculating estimated time of arrival, calculating descent gradient, and maintaining a fixed altitude. The computations are more accurate than the old ball park figures. However, many pilots experienced a difficult time as they began to learn to use the automation. Initially the workload seemed to double, but once pilots were experienced and learned the systems more thoroughly, the workload was greatly reduced.

The benefits of decreased workload enroute are beyond a doubt the most important purpose for the adaptation of automation in airplane industries. Automation provides the advantages of reducing manual workload and fatigue, relief from routine operations, increased economical use of the airplane, and the diminishing of the individual differences, as shown in Table 1.

4. Increased Situational Awareness. Automation has increased pilots' ability to know the status of the aircraft in real time. It makes it easier for pilots to determine whether the system is operating normally. The automation makes the reaction time to inflight changes quicker and more accurate because of the awareness of the equipment status. Even though the automation has made programming on the ground more time-consuming, in the air it gives the pilots more freedom for cross check and time for other aircraft functions.

As Table 1 indicates, these features increase pilots' capacity to do more jobs during flight and prevent pilots from making small errors. The automation features also provide pilots with the ability to precisely handle operations to make the flight safer.

The Disadvantages of Automation

1. The head down time increases. During initial automated operations the systems are new to a crew. Individuals have to spend excessive time in head-down situations. When system malfunctions take place soon after takeoff, too much "head down" time in the cockpit can occur. One captain indicated that many pilots spend too much time in the cockpit pushing buttons when they should be watching for traffic. Especially during approach, the crew tendency to update the FMS according to ATC directives causes two heads to be looking down and therefore no one is looking out of the cockpit for other traffic. This is obviously adverse to flying safety.

As shown in Table 1, one of the disadvantages of automation is increased mental workload. Even though the new technologies greatly reduce the physical workload, they also require an extra amount of time to command the automation keyboard. Barring

perfect efficiency, additional mental calculation can be created by automation.

2. Increased workload during preflight and programming. Unlike in the old airplane, the FMS system requires great amount of time to input preflight programming data. Workloads increase, especially in short drop and go missions, and when ATC changes flight routing. It requires reworking on tests and setting up departure information again. This greatly increases the pilot's workload. In the takeoff/departure and approach/landing phase, it demands heads-down time. Those phases already fall in the highest workload area which is dangerous to flying safety.

3. Data input errors. If we input incorrect data into the system, the system will take us to the wrong place (such as the DC-10 which crashed into Mount Erebus in Antarctica in 1979 and Korean Airlines Flight 007). If we merely rely on the FMS for navigation and do not check the entry properly, those accidents are likely to happen again.

As can be seen in Table 1, the most dangerous disadvantages are silent failure, false alarms, automation-induced failures, and the over-reliance on automation. Those cases mentioned above show that if pilots make a minor mistake by putting wrong data into the FMS systems, the outcome can be fatal and could occur with no warning before-hand.

4. Altitude problems. When altitude select is inadvertently deselected by moving the autopilot pitch trim knob, no aural warning or visual warning alerts the pilot. Even the smallest touch on the altimeter trim knob will disengage altitude hold. Altitude awareness is an absolute necessity. Furthermore, the pre-selected altitude is projected on the EFIS and the select knob has no detect feel. It was possible to set an altitude, say 17,000, glance

away, and then look back to see 18,000.

Table 1 lists one of the disadvantages of automation as the fault intolerance which may lead to large errors. This disadvantage is accompanied with another disadvantage, over-reliance. When those two disadvantages are put together, problems like the wrong altitude setting and other unforeseen accidents could happen.

Summary

In the 20th century, man first conquered the aerodynamic problem and successfully flew in the air in 1903. After 90 years of continued efforts of science and industry, the highly-automated airplane today is far safer than the original Wright brothers aircraft. However, new technology now challenges our human ability to understand and control it. Many accidents show that the difficulty of commanding the computer and computer mistakes can cause fatal accidents. The quality requirement for a pilot has never been higher. Besides the basic flying skill, another essential area is necessary for pilots to learn. This is the knowledge of understanding the automation functions and the skill to operate them. To fulfill those requirements, an effective training philosophy needs to be explored.

III. Training Philosophies

Previous research has indicated that although the automation alleviates pilot workload, it requires an inordinate amount of training to learn and operate at peak effectiveness

(Parrish,1991:66-70). It also indicates that training pilots in high technology cockpits has several new areas of consideration. Aside from basic airmanship and knowledge, certain pilot tasks have become increasingly important in highly-automated airplanes. It is not enough for pilots to be able to monitor their systems; they must also be able to understand the logic and the parameters within which the automation operates the aircraft (Wise, et. al.,1993:16). This chapter evaluates the current pilot training philosophies and the methods airlines use to qualify their pilots. That is important because airlines must apply a correct philosophy to train their pilots safely.

Basic Flying Skill Training

Airliners normally train their pilots in two phases. The first phase is called basic flying skill training phase. Student pilots receive their airline pilot rating through many channels and methods. This is done before the company sends its pilots to duty.

The definition of basic training is: that training conducted under the FAR part 61 (see appendix G) to meet the basic requirements of airliner pilots' knowledge and flying skill to guarantee flying safety. It can be viewed as the training that the major airlines have today for their pilots before they transition into highly-automated airplanes.

The Importance of Basic Flying Skill Training

Basic Flying Skill Training is important because it is the foundation of the pilots' training. It is the basic requirement a pilot should have to fly the airplane safely.

In a traditional airplane, pilots have to conduct their flight duty manually. It is

essential for a pilot to meet the Eligibility (FAR part 61.151), Aeronautical Knowledge (FAR part 61.153), Aeronautical Experience (FAR part 61.155) and Aeronautical (FAR part 61.157) requirements. When pilots meet those requirements, theoretically they should be able to demonstrate professional flying skill associated with their aeronautical knowledge to fly the traditional airplane or the highly-automated airplane, when in the manual mode, safely.

The basic training is important not only because it is essential in a traditional airplane but also because it is the first line of protection the airplane has from accident in the highly-automated airplane when the automation feature fails. No matter how much modern technology is present in the automation functions in all areas of the airplane control, when the system fails, only the skill of the pilot can prevent an accident from happening.

Charles E. Billings, formerly chief of aerospace human factors research division at the NASA Ames Research Center, said: "It is essential to keep a human pilot in command because of the large amount of uncontrollable variability in the air transport system" (quoted in Henderson, 1992:70). In fact, even though most airliners often discourage their pilots from flying manually because so much money has been spent on the automation, some operators like Delta and Federal Express are encouraging their pilots to use their own judgment to decide whether to fly the airplane manually or automatically (Hughes, 1992a:50). Most of the accident causes listed in Chapter II and Appendices could have been avoided if the pilots had been flying manually. Furthermore, researchers also indicate the concern of pilots who complain their basic flying skill has decreased since the

adaptation of the automation systems on airplane (Wise, et. al.,1993:212). It is obvious that in the highly-automated airplane the learning workload is doubled; the pilot not only has to learn the good basic flying skill, to efficiently control cockpit automation, the pilots need more training than those who fly non highly-automated airplanes; that is the FMS-based knowledge training.

The Government Training Requirement for Airline Pilots

Federal Aviation Regulations Part 61, Subpart F-Airline Transport Pilots section, lists the basic pilot recruit requirements. These regulations provide a baseline for all airlines to follow to recruit and train their pilots. These policies are essential to all airlines world-wide to have their airplanes airborne and transporting passengers. So, it is important to evaluate the FAR training policies to compare the present situations in a highly automated era.

Ground Training. (135.345) Pilots: Initial, transition, and upgrade ground training.

This training must include at least:

1. The certificate holder's flight locating procedures.
2. Principles and methods for determining weight and balance, and runway limitations for takeoff and landing.
3. Enough meteorology to ensure a practical knowledge of weather phenomena, including the principles of frontal systems, icing, fog, thunderstorms, windshear and if appropriate, high altitude weather situations.
4. Air traffic control systems, procedures, and phraseology.
5. Navigation and the use of navigational aids, including instrument approach procedures.
6. Normal and emergency communication procedures.
7. Visual cues before and during descent below DH or MDA.
8. Other instructions necessary to ensure the pilot's competence.

Pilots who complete this part of training gain a thorough knowledge about the flying environment, rules, and procedures. This part of training is important for flying the traditional airplane and the highly-automated airplane when flying it manually. However, the airlines which use the highly-automated airplane could not find a clear direction of how to train their new pilots to understand the automation features and limitations on the ground. Pilot, ATC, and automation interface problems are then embedded in this part of training.

The Flight Training. (135.347) Pilots: Initial, transition, upgrade, and differences flight training.

- (a) The training for pilots must include flight and practice in each of the maneuvers and procedures in the approved training program curriculum.
- (b) The maneuvers and procedures required by paragraph (a) of this section must be performed in flight, except to the extent that certain maneuvers and procedures may be performed in an aircraft simulator, or an appropriate training device.
- (c) If the certificate holder's approved training program includes a course of training using an aircraft simulator or other training device, each pilot must complete--
 - (1) Training and practice in the simulator or training device in at least the maneuvers and procedures in this subpart that are capable of being performed in the aircraft simulator or training device.
 - (2) A flight check in the aircraft or a check in the simulator or training device to the level of proficiency of a pilot in command or second in command, as applicable, in at least the maneuvers and procedures that are capable of being performed in an aircraft simulator or training device.

This flying section of training requirements is unclear. The highly-automated airplane can be flown either manually or automatically, and airlines can interpret this part differently. When their training is complete, pilots training in traditional airlines or training to manually fly the highly-automated airplane, theoretically have already met this

part of requirements—even though the pilots do not know anything about how to use the automation features in the cockpit. When pilots are actually sent to the highly-automated cockpit, they could use all of those automation systems if they want, but may never have been trained. This is a pitfall in the flying training requirement section.

Airliner's Approach to Meet Government Requirements

To satisfy the requirements of the FAR regulations and enroll enough pilot resources, other than hiring already experienced military retired pilots, airlines conduct many alternative training approaches to meet both the government and company needs. Several examples such as Lufthansa Airline's ab initio training program, China Airline's spectrum and advanced spectrum training program, and United Airline's collaborative program with Florida Institute of Technology all show various methods of airlines conducting their pilot training (details, see Appendix H).

The training programs conducted by each airliner meet the guidelines of the FAR regulations for proficiency. Furthermore, they strengthen the knowledge and skill of pilots through many different channels. Through these varied training methods, airlines meet their manpower needs, and complete their pilots' qualifications.

FMS Based Training

The Phase 2 training, or advanced phase, is transition training. Selected pilots are trained from Phase 1 traditional airplanes to highly-automated airplanes. With already qualified basic flying skills, the focus is then on how to use on-board automation systems to

effectively fly the airplane.

In a highly-automated cockpit, to know how to get the proper information quickly and correctly is an essential part of the training. When pilots are able to give the FMS correct commands, the FMS systems will then do the rest of the job. If the pilots do not know how to rule the computer, the airplane will not cooperate. So in the Phase 2 training, airliners have placed more emphasis on the FMS-based knowledge training.

It is essential that in a highly automated airplane the control process is as follows: man (give commands); computer (FMS system receives commands and gives orders); airplane (engine, elevator, rudder, follow pilots' order). A medium which stands between the direct command and indirect command to the airplane is the FMS system. The function of the FMS is to give more precise and correct controls of the airplane instead of depending on pilots' varied judgment to do so. In other words, if you can control the computer well, you can control the airplane well.

Definition of FMS Systems Training

The FMS training means to develop the pilot's understanding of the automation's capabilities, limitations, modes, and operating principles and techniques, basic mode setting as well as how to manage the system, instead of focusing on the basic flying skill training. Because of the FMS training's unique features and functions, this training is separated into two parts; the Skill-Based FMS training, and the Knowledge of Functional Theory-Based

FMS training.

A. The Operating Skill-Based FMS Training

In this thesis, the skill-based FMS training is defined as the training focused on teaching pilots how to quickly and efficiently operate the FMS systems in all flying phases. Training should focus on the following: during all flight phases, what key board should be input, where is that keyboard's location, what is the procedure, and what data need to be inputted, to efficiently conduct a safe flight. The operating skill-based FMS training does not emphasize knowledge of how and why the automation systems function. All that pilots need to know is the procedures and actions to perform certain maneuvers. The emphasis is then on how to do it quickly and correctly. It is a method to train pilots how to manage and integrate the FMS systems functions and performance by the flightcrew during transition training to the glass cockpit aircraft. The important areas are the processing of what, when, where, how much, and in which format should the pilots to know about the operation of the FMS systems. The purpose is to increase the pilot proficiency with regards to the automation systems and to reduce pilot errors.

Training Assumption. We need operating skill-based training because the evidence show that the input errors to the FMS systems under fairly severe time constraints, coupled with high workloads and high stress situations, have long been acknowledged as a severe problem (Lofaro,1991:884). Erroneous keyboard entry of data into FMS computer systems and other keyboard devices on the flightdeck has become a major problem. Data entry

errors can occur during initial programming and reprogramming of inertial navigation and other flight management systems which require manual programming. To minimize pilot error, requirements for training flight crews in the use of these devices should be generated.

B. The Knowledge-Based FMS Training In this thesis, the definition of knowledge-based FMS training is training focused on teaching pilots to know how the FMS system functions. Instead of learning what key should be punched in order to perform certain maneuvers, knowledge-based FMS training teaches pilots why punching that key will cause the airplane to maneuver that way. Pilots should know that, if they want the aircraft to take a specific maneuver, they must press the correct button for that action; that is, they must provide the automation systems with the command the engineers have designed it to recognize (Wise,et.al.,1993:254). In other words, they need to know what would happen when they punch a certain keyboard.

Training Assumption. Demosthenes et. al. indicate that pilots should be trained in the use of automated systems so they clearly understand all modes of operation, mode interaction, functional limits, and the design concepts for the process that automation uses to control the aircraft or systems (Demosthenes and Oliver, 1991:25). Veillette indicates that high technology offers many benefits, but the potential hazards of erring with these devices very often are quite severe, so pilots must be aware of the proper use of such equipment. This means more than just knowing how to program the device and being familiar with the functions of varying modes (Patrick, 1996:18).

The Difference Between Operating Skill-Based and Knowledge-Based FMS Training

The difference between skill-based FMS training and knowledge-based FMS training can be defined as the “bottom up” vs. “top down” approaches.

The typical “bottom-up” skill-based FMS training can be defined as “teaching pilots to learn the appropriate recipe for making their FMS work in standard or training situations.” But according to Wise et. al., this training does not enable pilots to acquire knowledge to adjust to novel situations while flying the line (Wise,et.al.,1993:18), which is to train for specific tasks, not an understanding of the FMS systems as a whole. Typical operating skill-based FMS training can be found in United Airlines, the Airbus industry, and Air Canada (see Appendix I).

The “top-down” approach or “knowledge-based” FMS training teaches pilots to understand the functional structure of the FMS and better handle novel situations. This training allows pilots to better predict the outcome of their FMS inputs, and encourages pilots to understand “why” and “how” the FMS works, its logic, and helps them in forming an accurate mental model (Wise,et.al.,1993:18). This training approach is yet to be developed by airlines and the Federal Aviation Administration.

The Importance of Phase Two (FMS-based) Training

The FMS-based training is important because a qualified pilot, according to his or her experience in controlling the airplane in his own way in a traditional airplane, might be

confused by the characteristics of the FMS system in a highly-automated airplane. Pilots must fully understand the character of the FMS system with its functions, capabilities, limitations, mode settings, operating principles and techniques. If the pilot does not know the system well and flies the airplane half on automatic and half on manual, it could be dangerous and the problem could be serious.

In the CAL A300 case, the pilots wanted the airplane to descend to intercept the glide slope, but the FMS gave the command to pitch up to go around in response to the activation of the go-around switch. In a situation like that, the common sense of a pilot does not make sense anymore. When those pilots pushed the yoke, the trimmable stabilizer gave the counter command to cause the nose to pitch further up instead of bringing the nose down as expected. The Autopilot and Go-around mode were doing their job. That is the feature of automation.

The Air New Zealand and KAL 747 accidents give us further indications of the importance of familiarity with the FMS systems issue. It was the pilots' input of the wrong data into the FMS systems instead of flying skill deficiency which caused each of those fatal accidents. If those pilots had input the correct data into the FMS system, those trips would have been uneventful. Quite a different outcome would have resulted.

Referring to the accidents discussed earlier, we can see that the FMS systems were only "doing their job" when accidents happened. The flying control of China Airline's Airbus A300-600R followed the go-around and autopilot command to have a pitch up

attitude. If the crews had simply let the FMS systems control the airplane, it would not have become an accident. The Air New Zealand DC-10 and KAL B-747, too, followed the preprogrammed data properly and flew it correctly but the outcome was a disaster. Those accidents were not flying-skill related. They were the results of erroneous commands that the pilots made which turned the outcomes into fatal accidents.

Those cases indicated that when a pilot does not know the FMS system functions, once the malfunction or confusion happens, the pilot can do nothing. The outcome is unpredictable and often causes chaos. When a pilot fully understand the FMS systems, pilot has to do nothing. The FMS system will do everything for pilot. That is why the FMS-based pilot's understanding of the automation's capabilities, limitations, modes, and operating principles and techniques stands out as an important issue in highly-automated airplane training. Many experts have already detected this importance. John K. Lauber, a member of the National Transportation Safety Board said: "We have left some gaps and run ahead of our ability to teach humans how to use sophisticated cockpit equipment such as flight management and flight director systems properly." "Although the technology and reliability of automated systems are impressive and have benefited the airlines, what is missing are principles, rules and guidelines defining the relationships between that technology and the humans who operate it" (Phillips,1992:40).

Summary

The FAA regulations provide the basic rules for airliners to follow for recruiting,

training, and deploying their pilots. However, Part 61 (135.345) and (135.347) clearly list the requirements for Phase 1 basic training, but provide no specific requirements for Phase 2 FMS- based training. To meet the Phase 1 training requirements, airlines have followed different channels to train their pilots, all of which have proved to be effective. Apparently, what we need to do is to provide a better direction for airline to train their pilots during the Phase 2 FMS based training which the FAA regulations do not specifically address.

Conclusion

The traditional training approaches focus on the flying skill training and basic aeronautical knowledge. However, in the highly-automated airplane, because of its unique automation features, the flying skill portion of training seems to be ignored. However, pilots believe not only that they need more training for basic flying skills, but also that they need more training in operating the flight management systems associated with the knowledge training of how those systems function. Among those training requirements, with the limited resources and time available, we have to find a balance among them.

According to the FAA regulations, all airliner pilots must receive adequate basic flying skill training and be qualified. The question areas are the training areas dealing with the automation features. With no strict requirements or regulations, airliners and pilots themselves train in a self-disciplined manner. From a safety point of view, finding the best balance between the skill of operating the automation systems and the knowledge of how

those flight management systems function is a focal point for our study.

IV. The Balance of Skill and Knowledge Based Flight Management Systems Training

In 1989, the Air Transport Association of America published a book about automation and its conflict with human factors (ATAA:1989). It listed some of the potential issues arising around the new, automated aircraft which can be seen as the general summary of new problem areas, shown in Table 2.

Table 2. The Problem Areas of the Highly-Automated Airplane

1. Reduction of workload in low workload phases of flight (i.e., long-haul over water).
2. Increase in workload in high workload phases of flight, (i.e., terminal area).
3. A potential for substantially increased head down time.
4. Difficulty in recovering from an automation failure.
5. Reluctance of flight crews to take over from a malfunctioning automated system.
6. Degradation of pilot/controller basic skills.
7. Complacency, lack of vigilance, and boredom.
8. Introduction of unanticipated failure modes.
9. Difficulty in detecting system errors.
10. Incompatibility between advanced automated aircraft, existing ATC capability and the rest of the fleet.

The problems detailed in Table 2 highlight the importance of training concerning the automation system's function and skill and indicate that there is a need to develop a training philosophy to explore the advantages and to eliminate the disadvantages of the highly-automated airplane. It is essential for us to provide better training to explore the benefits of reduction of workload in low workload phases of flight and to reduce the disadvantages of increasing workload in high workload phases of flight, including increased head down time,

difficulty in recovering from an automation failure, reluctance of flight crews to take over from a malfunctioning automated system, degradation of pilot/controller basic skills, difficulty in detecting system errors, and incompatibility among advanced automated aircraft. Those are the key points for developing FMS-based training.

In Chapter III, we identified that basic flying training is guided by strict principles. All pilots qualified to obtain their airline pilot license must maintain an equal level of quality in all areas. However, the training requirements for the highly-automated airplane from the government are vague. Different companies have different principles to train their pilots to work with the automation. In this chapter, I would like to suggest a better training philosophy for inclusion in the highly-automated cockpit training to improve flying safety. Especially, I would like to address the balance between the two kinds of training dealing with FMS systems. One is training for the skill to operate the Flight Management Systems in highly automated airplanes, and the other is training to understand the functional theories of the Flight Management Systems. In brief, my purpose is to reach a balance between skill- and knowledge-based Flight Management Systems training to deal with new technology.

Suggested Training Philosophies to Deal With the Automation Problems

Since we have defined the different training philosophies between skill- and knowledge- based FMS systems training, it is important now for us to apply them to the problem areas of the highly automated airplane to find a better solution to improve flying safety.

Matrix 1 : An Evaluation Matrix of Pilot Problem Areas of Automation

Matrix 1 (Table 3) compares the general problem areas and two FMS training philosophies in each column to provide a better approach to cope with them. The general problem areas are defined by the Air Transport Association of America (ATAA:1989). In this matrix, the suggested solutions are listed right; an analyzed explanation is provided below the matrix. The purpose of these solutions is to provide pilots with information about how they spend their time in FMS training.

Table 3.

The Problem Areas of Highly Automated Airplane and the Relevant Training

Problem Areas of Highly Automated Airplane	Operating Skill Problem	Knowledge Problem	Training Needs
Problem1. Increase in workload in high workload phases of flight, (i.e., terminal area).	X		Skill-Based Training
Problem 2. A potential for substantially increased head down time.	X		Skill-Based Training
Problem 3. Difficulty in recovering from an automation failure.		X	Knowledge-Based Training
Problem 4. Reluctance of flight crews to take over from a malfunctioning automated system.		X	Knowledge-Based Training
Problem 5. Introduction of unanticipated failure modes.		X	Knowledge-Based Training
Problem 6. Difficulty in detecting system errors.		X	Knowledge-Based Training

Problems 1 through 6 listed in first column can each be defined as operating-skill based or knowledge-based problem according to the data (pilot comments) collected by the Embry-Riddle study (Appendix J). By referring to the definition and function of the operating

skill-based and functional knowledge-based training, the suggested training need is then provided in the last column.

Result Analysis

Problem 1 Increase in Workload. The problems of increased workload in the high workload phase of flight occur primarily in the takeoff/departure and approach/landing phases. In those phases, knowing the procedure and process to input data is relatively more important compared to knowing what the functions of those pieces of equipment are.

Some typical pilots' comments, collected in the Embry-Riddle study, high-light the need to train pilots to familiarize themselves with the operation skills of the FMS systems to reduce the workload during high workload phases (Wise, et.al.:1993). Typical comments include:

Increased Workload In Preflight Phase

"Increased in some phases - preflight programming versus filling out old card manually because programming requires entering more parameters than old card."

"Increases workload on the ground before flight due to more tests and set-up of departure information."

"Obviously workload has increased in the preflight stages whether we program a flight plan to computer disk in the office or work on the FMS in the aircraft."

Increased Workload When ATC Makes Change

"Automation has increased workload. If I haven't flown it in several weeks as well as in rusted situations, i.e., changed runway at last moment, or late issuance of a clearance."

"Workload is increased during approach phase with ATC changes to the arrival routing or the approach."

"Increased workload in terminal area and last minute ATC changes."

"Workload is increased during descent and approach, if there are changes being issued by ATC, and if you try to insert those changes into FMS. The resultant head down time is dangerous."

Increased Workload During Descent/Approach

"Workload can increase dramatically on descent or approach. When flying internationally, the unexpected can keep the non-flying pilots heads-down a lot."

"Most programming of FMS can be done before aircraft taxis out for takeoff. Any preprogramming done on approach or departure adds tremendously to workload and in my opinion, should be kept to a minimum."

The Suggested Solution. According to the problems stated above by airline pilots, it is obvious that training in FMS operating skill is necessary. To efficiently reduce the workload during those already heavy workload situations, more efficient operating skills of the FMS systems are required. When pilots know how to manage and integrate the FMS systems and the processing of what, when, where, how much, and in which format should the pilots act in relation to the FMS systems, and can do so quickly and correctly, it will reduce the feeling of work overload and can increase flying safety by reducing possible erroneous entry to the keyboards. That is the purpose of operating skill-based FMS training.

Problem 2 Increased Head Down Time. The head down time increased because pilots are trying to figure out what to input and how to do this in the cockpit. This reduces their

capability of looking for traffic. However, with basic flying skill inbred, pilots can transfer to manual flight in case of emergency. Then, those problems are not life threatening. Many typical comments by pilots are collected in the Embry-Riddle study:

“During initial FMS/EFIS ops, individuals spend excessive time in heads-down situation. Become more heads-up as experienced is gained.”

“A new systems or a pilot just introduced to FMS/EFIS can have too much heads down time, therefore, decreasing safety considerably.”

“The placement or location of FMS keyboards are not user friendly-lots of head down and looking back-not outside.”

“During approach, crew tendency to update the FMS according to ATC directives causes two heads looking down and therefore no looking out the cockpit for the traffic.”

The suggested solution. Reducing the head down time is also related to the proficiency of operating the FMS systems. The definition of operating skill-based FMS training is essential to solve the problems listed above. So the better solution to those problems is training in operating skills for the FMS systems.

Problem 3-6 System Errors Problem. Problems 3-6 actually are the main causes of fatal accidents. In these categories, if the pilot does not know how the systems function, an accident is more likely to happen. It is difficult to identify the problem and difficult to solve the problem. Follow lists many comments from pilots about the confusing aspect:

“There were many initial problems due to lack of familiarization and experience. ATC frequencies were lost. Altitudes not captured. Screens went blank (flight plan erased).”

"Autothrottle creates considerable confusion on takeoff, initial climb out and on go-around."

"Main problem was calling up the correct display on the screen for the function that I wanted to use or modify in a flight plan."

"Initially it is extremely difficult to figure out exactly how to program or pull up the data you want, i.e., how to get the correct page up to program the system."

"In the black cockpit as long as everything is working nothing is enunciated, then when there is a malfunction, recognition is slower because you never see the bezels illuminated in normal conditions, so familiarity is lacking."

"It has greatly improved our ability to see the big picture. At the same time, it has lowered our awareness of problems that become apparent upon the failure of a major EFIS or FMS component. We tend to depend too much on the electronic displays of our situation rather than keep up on the analog (brain) functions."

The suggested solutions. According to the definition of the Functional Knowledge-Based FMS training, the better solution for those problems stated above is understanding the function theories of the FMS systems. To understand all modes of operation, mode interaction, functional limits, and the design concepts for the process that automation uses to control the aircraft or systems is the key issue to solving those problems.

Matrix 2: The Pilot Response and the Suggested Training Need.

Matrix 2 (Table 4-7) identifies better training to reduce the problems encountered by the pilots who fly the highly-automated airplane. The data base of response to problems on this matrix comes from the questionnaire conducted by Embry-Riddle (for details, see Appendix J). In these matrixes the first and second highest ranking problems is selected for

analysis. A comparison of the definition and function of the skill-based and knowledge-based training is again applied in these matrixes to conduct the suggested training needs.

Q.1: "Briefly describe an operational problem--that you personally know of--involving the automated features of your aircraft that could have had a negative consequence" (p.163).

Table 4. Frequency of categorized responses for open-ended question 1 (n=339)

Response Category	Frequency
Heads-Down/Inside Cockpit	47
Data Input Error	38
Altitude Problems "Busts"	25
Design/Interface	22
Training	20
Crew Communication	19
Equipment Failure	17
Check Data Entered	15
Autothrottle Incidents	14
System Software	13
Air Traffic Control	12
System Induced	12

Ranking	Problem	Training Need
Highest Ranking	Heads-Down/Inside cockpit	Operation Skill
Second Ranking	Data input error	Operation Skill

Q. 1 asked about the operational problem that pilots believed involved the automated features of their aircraft that could have had a negative consequence. Both the highest and second highest ranking fall under operating-skill as main problem. One CE-650 Captain commented, "When systems are new to a crew, too much heads down in the cockpit. If system malfunctions happened soon after takeoff, too much head down in cockpit would

cause serious problem.” In Chapter 3, the training assumption for the operating skill is to reduce the possible input errors to the FMS systems under fairly severe time constraints, coupled with high workloads and high stress situation. That is the purpose of operating skill-based FMS training, to reduce the negative consequence of automated features by minimizing the pilot error on erroneous keyboard entry.

Q3: “What operational features should be added to improve safety and/or reduce workload” (P.170).

Table 5. Frequency of categorized responses for open-ended question 3 (n=291)

Response Category	Frequency
Simplify Software	43
Standardize Keypads and Location	27
Heads-up display	22
Traffic/Collision Avoidance system	16
Training	15
Put controls higher/more forward	14
Better/Expanded Databases	11
Standardization	11
Minimize display clutter	9
Other (AOA, back-to-basic-button)	9
Aural Warnings	5
Keep Past Waypoints Alive	4
Terrain/Obstacle Information Displayed	4
Airspeed Trend/Thrust Vector	3
Clear View of EFIS	3

Ranking	Problem	Training Need
Highest Ranking	Simplify Software	Functional Knowledge
Second Ranking	Standardized Keypads and Location	Operation Skill

Q. 3 asked which operational features should be added to improve safety and/or reduce

workload. In this response, the suggestion to simplify the software high-lighted the problem of understanding the FMS system. The skill-related problem of standardized keypads and location ranked second. The insufficiency of knowledge of FMS systems with a complex software could cause huge problems. Pilots want a simpler software which reflects their belief that high automation features are too complex for them. Thus, before the engineers create a simplified software, the training to understand the functional theory of the automation software is a must. This is critical to aviation safety.

Q4B: "What effect has automation had on your workload? Where has it increased workload?" (175).

Table 6. Frequency of categorized responses for open-ended question 3 (n=129)

Increased Workload responses	Frequency
Preflight Planning	56
ATC Changes	19
Descent/Approach	15
Initial Learning	7
Terminal Area	7
Takeoff/Departure	6

Ranking	Problem	Training Need
Highest Ranking	Preflight Planning	Knowledge + Skill
Second Ranking	ATC Changes	Operation Skill

Q. 4B asked about the effect of automation on increased workloads. Preflight planning ranked highest. This problem involved both what data are needed and how to apply them. As a CE-560 Captain commented : "Increases workload on the ground before flight due to more tests and set-up of departure information." The need to be familiar with the operating skill to handle the set-up and test quickly and correctly is essential to reduce the workload.

Both skill and knowledge training are needed to solve this problem.

In this open-ended question, ATC changing directions, causing an increased workload as pilots reorganized their program, ranked as the second most important problem. As pilots commented "Initial learning phase is significantly increased. After about 20-30 hours of hands on experience workload decreases." Pilots need to practice operating skill more to quickly and correctly react to the ATC change by inputting necessary data into the FMS systems.

Q5C: "Describe any problems that you had in an automated aircraft during (a) your initial operating experience, and (b) your subsequent operating experience" (p.189).

Table 7. Frequency of categorized responses for open-ended question 5 (n=122)

Initial Operating Experience	Frequency
General Confusion	9
Getting Use to EFIS	7
Calling up Correct Page/Display	6
Heads-Down/Inside Cockpit	5
Push Wrong Buttons/Slow Entering Data	5
Too Much Going On	5
Uncertainty in Programming	5
Other	2

Ranking	Problem	Training Need
Highest Ranking	General Confusion	Functional Knowledge
Second Ranking	Getting Use to EFIS	Operation Skill

Q. 5C asked pilots about problems they had in an automated aircraft during (a) the initial operating experience, and (b) subsequent operating experience. Getting confused ranked as

the highest problem, which falls into the knowledge base of training area. As a Captain commented "Autothrottle creates considerable confusion on takeoff, initial climbout and on go-around" and "Main problem was calling up the correct display on the screen for the function that I wanted to use or modify in a flight plan." With these kinds of confusing activities, the flight duty could be dangerous. Pilots need to know the functional theories of these modes. This indicates the need to strengthen knowledge-based FMS training. The second-highest ranking experience is getting used to EFIS. This is mainly a skill-based problem. As pilots commented: "Getting used to the EFIS display was the hardest. Initially it is extremely difficult to figure out exactly how to program or pull up the data you want, i.e., how to get the correct page up to program the system." When pilots practice more on the operating of the EFIS system, this problem can be reduced. However, lack of familiarity with the operating skill of the EFIS can cause pilots to be slower in completing their tasks, and the confusion of the EFIS system can be fatal. Therefore, both operating-skill and functional knowledge of that system should be developed.

Summary

After evaluating these two matrixes, we can conclude that the two FMS-based training philosophies can each solve part of the problems of the highly-automated airplane's features:

1. The operation skill-based Flight Management Systems training can improve the proficiency and reduce heads-down time and help pilots become more familiar with the automation operating procedures.

2. The functional knowledge-based Flight Management Systems training can solve the problem areas of difficulty in recovering from an automation failure, difficulty in detecting system errors, and reluctance of pilots to take over from a malfunctioning automated system.
3. In normal and routine operating conditions, the operation skill-based Flight Management Systems training is more helpful; however, in situations in which an automation system malfunction happens or in abnormal automation function situations, the functional knowledge-based Flight Management Systems training is exclusively important.
4. Lack of operation skill to operate the flight management systems will cause inefficiency and increase the heads-down time during flight; lack of knowledge of the functional theory of the flight management systems in emergency situations will cause fatal accidents.

Cases Analysis (CAL and Airbus) With the Suggested Training Philosophies

The CAL A300 and France A330 fatal accidents in 1994 can be seen as typical accidents characteristic of highly-automated airplanes. They both demonstrated the characteristics of silence, surprise, and unpredictability of the highly-automated airplane.

After defining the function of operating skill-based FMS training and knowledge-based FMS training and suggesting a problem-solving method in Matrix 1 and 2, the next concern would be to apply those training philosophies to the accident cases. The purpose of this step is to demonstrate whether the assumptions are adequate or.

China Airline Case. Referring to the China Airline Flight 140, Airbus 300-600R accident at Nagoya, Japan, April 26, 1994, we note that preliminary analysis of the crash cause suggests that a shift from manual to autopilot resulted in cockpit crew confusion. The digital flight data recorder and the cockpit voice recorder show that the crew engaged, disengaged, and then re-engaged the take-off/go-around switch:

The cockpit voice recorder indicates a change in the landing-mode. It was at this point that a crew member inadvertently activated the takeoff/go around (TOGA) switch. The airplane reverted to automatic go-around mode, and began to fly above the glide slope. The captain warned the first officer twice that it was engaged. However the TOGA could not be disengaged. The First Officer applied nose down elevators in an effort to recapture the glide slope. The airplane reacted as rose above the glide slope, and the pilot was still applying nose down elevators input.

At this point, the Airbus analysis shows that the crew engaged the autopilot. With the autopilot's autotrim function deflected, the trimmable horizontal stabilizer (THS) was moved to its maximum nose-up deflection. Since the flight directors were still in go-around mode, the autopilot also was in go-around mode. As a result, the aircraft was put in a nose-up attitude.

Still, the crew continued to apply nose-down inputs by overriding the autopilot as it tried to recapture the glidepath for a landing. Such a tactic does not work because as soon as the inputs are stopped the autopilot returns to flying its original go-around flight path. In such a configuration, since the stabilizer efficiency is greater than that of the elevator, the aircraft could reach an abnormal pitch-up angle leading to an airspeed decay as the pilot puts stronger force on the flight control column.

At about 570 feet, both autopilots were disengaged. At about 400 feet, the alpha floor function (angle of attack) was triggered. Both engines accelerated normally to maximum thrust. Coupled with the THS at maximum nose-up deflection, the pitch attitude achieved at least 36 degree. Flap/slats were retracted from 30/40 degree to 15/15 degree, but the aircraft was in a stall from which it could not recover. (Mecham:1994)

This case highlighted many presently existing automation problems shown in Matrix

1: the difficulty in recovering from an automation failure, reluctance of flight crews to take over from a malfunctioning automated system, introduction of unanticipated failure modes,

and difficulty in detecting system errors; and in Matrix 2: the general confusion issues. As we rank those problem areas, they are mostly FMS knowledge-based problems.

Mr. Bernard Ziegler, Airbus senior vice president of engineering and former chief test pilot commented on this accidents:

- Selection of the go-around mode during approach, causing the autothrottle to give go-around power. The autopilot was not connected, but the flight director bars would command a go-around.
- Engaging the autopilot after the go-around had been selected. The autopilot will engage in the mode used by the flight director, here causing the aircraft to pitch up. "It's very hard to understand why the autopilot was engaged." "Maybe the pilot expected to be more comfortable with the autopilot on, but forgot it was in go-around."
- The crew fought the autopilot to push the aircraft back to the glideslope. The autopilot countered by moving the stabilizer trim to within roughly 1 degree of full up.
- As the aircraft was pitching up through 40 degree at 115 kt., the crew retracted the flaps to up, increasing the stall speed and further increasing the pitch-up moment (Dornheim:1995).

After analyzing Ziegler's comments and comparing the three types of training discussed earlier (basic flying skill, FMS operating skill, and FMS function knowledge), we can see that this accident does not appear to be due to pilots' flying skill nor FMS operating skill. Actually CAL vice president/Flight Operations Zhang Guang indicated that the First Officer had done very well on his transition, scoring 98 out of 100 (Sekigawa,1995:32). It was the lack of FMS functional knowledge which caused the accident. If the pilots had fully understood the theory of the FMS system, they would not have been confused about the situation. The pilots could simply have let the autopilot conduct a go-around. However, the difficulty of detecting the problem and confusion caused man/machine

conflict and resulted in a crash.

After analyzing this case, we can conclude that if the pilots had selected the manual control and applied their basic flying skill at that moment, the accident could have been avoided. But as to why the pilots chose to manually control the airplane and fought with the automatic command, the answer is more likely that they did not thoroughly understand the theory of the function of the A300 flight management systems. This conflict fell into the problem areas of difficulty in recovering from an automation failure, reluctance of flight crews to take over from a malfunctioning automated system, introduction of unanticipated failure modes, and difficulty in detecting system errors.

France Airbus-A330 Case. On June 30, 1994, a GIE Airbus Industry owned-Airbus A330-322 crashed at Toulouse-Blagnac airport for a test flight mission. All seven crewmembers were killed. The accident description follows:

For the need of that test flight, that takeoff was made with a very after CG. The airplane climbed to a high pitch attitude, and the crew engaged the autopilot and simulated a left engine failure. Within 5 seconds after takeoff, several attempts to engage the autopilot were unsuccessful. After it was engaged, activation of the autopilot was delayed.

The captain reduced the thrust on the left engine to idle as soon as the autopilot was engaged and then cut off the blue hydraulic system. Immediately after it activated, the autopilot switched to altitude acquisition, due to the high aircraft climb rate. From this moment, the ALT mode control law pitched up the aircraft in attempt to reach the selected altitude. Automatic go-around (Alpha floor protection) then activated and was immediately stopped by the captain who reduced to idle the right engine as soon as roll control was lost to rapidly recover symmetry on the roll axis. Under these conditions, an indication of invalid information was sent to the flight control

computers by the inertial reference units, which caused the flight control system to revert to direct law. The pilot managed to regain control too late to avoid impact with the ground. The aircraft crashed with a pitch attitude of around -15 degree. (A330 Crashed," 1995:72)

In this case, the unique highly-automated accident characteristics of silence, surprise and unpredictability were once again shown. This test A330 crash raises new questions about highly automated, state-of-the-art glass cockpit systems, pilot interaction with such systems, and the risks tied to the flight crew's overconfidence in them (Sparaco,1994:20). The autopilot suddenly switched to the altitude acquisition mode and started to perform the designed function. When this occurred, the situation at that moment exceeded the pilots' expectations. Even though the captain tried to recover from the automation command, it was too late. The investigating team also cited other key factors:

1. Selection of a 2,000 feet altitude autopilot setting. The absence of pitch limit protection in the autopilot's altitude acquisition mode played a decisive role in the accident.
2. Selection of the takeoff-go around (TOGA) maximum power setting for the flight. The crew should have selected the lower "Flex 49" power setting (Flex 49 is a variable power setting that provides full takeoff thrust at a maximum outside temperature). After the left engine's throttle was reduced to idle as part of the test, asymmetric power conditions became extreme.
3. Selection of a -2.2 degree trim setting. A zero setting have been preferable to accommodate the aircraft's after C.G. loading.
4. An imprecise distribution of tasks among crewmembers.
5. A tardy decision by the pilot-in-command to regain manual control after the emergency developed on autopilot. (Sparaco,1994:20)

However, because the captain had adequate knowledge about the automation system functions, we assume that if captain had had enough time to correct that situation, he should have been able to solve the problem and avoid an accident. This case did show

that the automation could go wrong without any warning or pilot input error. The key point then is “can a pilot solve the malfunction of automation quickly and correctly?” In this answer, as I have already defined on the definition of knowledge-based FMS training, the need is for knowledge-based training to understand the functions of the automation systems.

Conclusion

After evaluating the purpose and function of the operation skill-based FMS training and Functional Knowledge-Based FMS training, we can conclude that operating skill can help pilots reduce head-down time and decrease workload during preflight/ re-programming the FMS systems. Pilots can more quickly and more efficiently command the FMS systems during flight and can avoid mistakes like punching the wrong button. This is absolutely helpful in routine and normal flight. However, in abnormal or emergency situations, merely depending on the skill of operating the flight management systems is not adequate. On the other hand, the functional knowledge-based FMS training is helpful to analyze the system functions and solve the abnormal automation problems of the automation systems. Pilots can gain benefits from functional knowledge-based FMS training to better recover from automation failure, becoming more willing to take over from a malfunctioning automated system and more easily detecting system errors.

V. Conclusion

The Highly-Automated Airplane and Safety

The safety record has proved that the highly-automated aircraft, despite some accidents or incidents, is safer than the old generation airplane operated by the airlines. David indicated "Airbus did not have a fatal accident for 16 years before the A320 crash at Habsheim in 1988. The A320 has experienced 2.5 hull loss accidents per million departures compared with 6.14 for the Boeing 707." (Hughes, 1995c:53).

From many pilots' point of view, automation enhances safety and reduces the workload. As a typical response from Embry-Riddle Aeronautical University's attitude survey shows "Automation reduce the workload greatly - makes the flights much smoother" (G-III, CL-601 - Captain.). That comment highlights the positive consequence of adaptation of automation systems in highly-automated aircraft.

Training is Essential to Safety

However, to some pilots, especially those who are not familiar with the automation systems, the highly automated aircraft seems dangerous. "Why did it do that?" was the most common remark. Some comments from pilots indicated their initial problems due to lack of familiarization and experience: "ATC frequencies were lost." "Altitudes not captured." "Screens went blank (flight plan erased)." "Flight director modes mis-selected." Those

experiences all highlight the importance of proper training for highly-automated airplane. Even though Chapter 4 suggested that from safety's point of view, among the three training parts, the FMS functional knowledge-based training is the most important, we can not ignore the equal importance of the other two training parts.

No matter what kind of airplane we are talking about, the basic pilot skill should always be emphasized. That is the bottom line to protect the passengers' lives. Today, the airplane designers presents many types of FMS systems that "can do" a lot of tasks to assist pilots. On the other hand, airlines have to train their pilots "how to do" to use those automation systems. The evidence shows that the most dangerous situation is when the pilot does not know the automation system well, yet tries to fly the aircraft automatically.

Besides the basic flying-skill training, pilots have to be trained by the operating skill-based FMS training to know the important areas of what, when, where, how much, and in which format to operate the FMS systems and to increase the pilot proficiency and to reduce pilot errors toward it.

Most importantly, pilots need the knowledge-based FMS training for understanding the functional structure of the FMS systems and be able to better handling the novel situations in emergency. This training allows pilots to better predict the outcome of the FMS outputs, and understanding "why" and "how" the FMS works with its logic, and enables pilots to have an accurate mental model.

The Missing Part of the Training

Under the FAA regulations, pilots can be trained in a traditional airplane and then be sent to an airplane with highly-automated features. Also, because of lack of specific FAA regulations on phase two training (as discussed in Chapter 3), the training philosophies in most airlines are ambiguous. Many airlines keep this part of training as classified material. However, the questionnaire data collected by Embry-Riddle University (Wise, et.al.,1993:181), indicate a shortage of phase two training and reflects the need for that.

Those sample pilot comments identified the missing part of the current training program:

“I didn’t have any initial training other than reading the manual myself and the chief pilot giving me hands on pointers on a trip” (CL-600/601-3A, G-1159-Capt.)

“My initial training involved myself on the ground with a manual and sitting in a powered up electronic system. Then I went on a trip and was given instruction on the way. This is very typical. Some pilots don’t even have the desire to sit in the aircraft on the first trip” (CE-550/650-Capt.)

“There was none. We learned on the job and it was difficult. There were many mistakes and we were lucky not to get violated. Not recommended.” (G-III-Capt.)

“No initial training was received - this is my greatest concern as we keep advancing in automation. Training institutions and manufactures must get together and offer initial as well as current training to pilots who will be flying these systems. Technology is moving very fast; let’s be sure we are on the same page” (G-III, CE-650-Capt.)

It is true that airlines have to use their employees efficiently. They may not have enough time to both deploy their crews on the job and at the same time dispatch them to training in a simulator. Some airliners do not even have enough simulators for pilot training. Part of this problem can be seen when as the newer model airplane rolls off the production line, and the simulator is still on its way to development. More frequently,

when an airplane changes its software design for modification, the simulator can not keep up with the change (Wise,et.al.,1993:253).

Those comments collected above in the Embry-Riddle study indicated that emphasis should be placed on automation knowledge and skill training. Poor training materials like lack of simulators or mock-up cockpits and improper emphasis on simulator training and improper training philosophies all contribute as major defects of phase two training.

Currently many suggestions and recommendations have been made in many fields by people who are concerned about the insufficient training in the highly-automated era. FAA and major airlines associated with airplane manufacturers are all working on research to improve current inefficiencies. The FAA signed the Advanced Qualification Program (AQP) rule on September 26, 1990. This regulation is designed to improve aircrew performance and allows certification holders that are subject to the training requirements of Parts 121 and 135 to develop innovative training programs that incorporate the most recent advances in training methods and techniques (Kern,1990:3). FAA is also preparing to create new rules to cope with those recommendations received from the flight crewmember training work group of the Joint Task Force (Wise,1990:3).

Recommendation

Automated aircraft are taking over the skies. Glass cockpits continue to receive mixed reviews from pilots. Some pilots who fly highly-automated aircraft say they have never been busier, even though the purpose of automation feature was to reduce pilot workload

and increase safety (Hughes,1992a:50). Some pilots enjoy it and anticipate the next generation of automation.

No matter how much progress the technology has achieved, pilots are still the final decision-makers in the cockpit. Their decisions and ability to operate the airplane will decide the result of a flight. The pilots' goals are to safely operate and complete the flight; their role is to command the operation of the aircraft, using all available resources to achieve the goal; their functions are monitoring, planning, communicating, controlling, operating, and most importantly, making the final decision (Demosthenes and Oliver, 1991:22). The pilots' decisions and abilities to control the highly automated airplane greatly depend on the degree of training they have received.

The modern highly-automated airplane has its unique flight character and unique problem areas and requires special training to deal with them, training which is different from the traditional training. Ronald Lofaro of the FAA summarized the new problems created by the automation:

1. Too little workload in some phases of flight and too much workload associated with reprogramming when flight planes or clearances are changed.
2. The potential for substantially increased head down time.
3. An inadequate cognitive map, or situational awareness, of what the system is doing, making recovery from automation failures sometimes problematic.
4. Hesitancy of humans to take over from an automated system, even when there is compelling evidence of a problem.
5. Degradation of basic skills.
6. Job dissatisfaction associated with the lack of a challenge.
7. Complacency, lack of vigilance, and boredom. (Lofaro:1991:880)

The trade off of advantages and disadvantages of the highly-automated airplane must be carefully evaluated by the pilots according to their experience and capabilities. To the

pilots themselves, when to use automation and when to use manual flight is a decision made according to their ability to conduct a safe flight. That is the bottom line for pilots to consider. To conduct a safe flight in the highly-automated airplane in all situations, normal, abnormal, and sudden failure of the automation systems, the proper training should be given to each pilot to cope with different situations.

Besides those recommendations of balance of pilot training, the airlines, the FAA, and the aviation industry should also provide crewmembers sound training tools to assist them. Currently, the airlines' greatest need is a guiding principle to efficiently train their crewmembers. Without those regulations, we can not guarantee the quality of pilots who fly the highly-automated airplanes. Also, the checkride philosophies and evaluation criteria should undergo some degree of change to fit the safety needs in the highly-automated airplane cockpits. Currently, pilots of many airlines are not required to perform recoveries from most types of unusual attitudes in training or on checkrides, and training programs are still strongly oriented toward acquisition of the necessary knowledge and development of skills required to pass a checkride. Little concern is directed toward the ability of the crew to accomplish the job- related objectives or to effectively manage the resources available on the flight deck (Ekstrand,1990:8). However, fatal accidents involving highly-automated airplanes all indicate the ability to recover from an automation system's malfunction or failure is important to guarantee aviation safety in the highly-automated airplane. In response to the new technology environment, we need to expend efforts to integrate all three skills: the basic flying skills, the operating skills to operate the FMS systems, and the

thorough knowledge of the functional theories of the FMS systems to improve the flying safety in the highly-automated era.

Appendix A: Acronyms

ASRS aviation safety reporting system
CDU control display units
CRT cathode ray tube
ECAM electronic centralized aircraft monitor
EFIS electronic flight information systems
EICAS engine indicating and crew alerting systems
FAC flight augmentation
FCC flight control computer
FMCS flight management computer system
FMS flight management system
MCP mode control panel
PFD primary flight display
PMC performance management computers
SID standard instrument departure
TCAS collision avoidance system
TCC thrust control computer
VNAV vertical navigation

Appendix B: CAL A300 Crash Moment Cockpit Voice Record

First officer Chuang Meng-rong was piloting the airplane with Captain Wang Lo-chi when Nagoya tower advised that CAL flight 140 had passed the outer marker of runway 34. It was 8:12 at night with clear visibility and wind from 290 degree at 6-mph. At 8:14 PM the TOGA engaged.

8:14.10 autopilot ON.

Captain: "You, go-lever is ON. Reduce it a little.", "Push it down. Disengage throttle. It's too high, too high." "It's on go-around mode."

Captain: "Don't worry. Push it again slowly. Keep it with your hand."

"Push it again, push it again, push it again." "It's still in go-around mode."

8:14.40 Auto-pilot disengage warning sound appeared. Auto pilot "off".

F/O: "Still it could not be pushed."

Captain: "Don't worry. Do it calmly." "Ok, I try."

F/O: "Disengage. Disengage."

Captain: "What is this?"

F/O: "Disengage"

Captain: "Go lever." (DFDR showed go lever operated).

Captain: "Goddamn it! Why it comes in this way?"

F/O: "Nagoya tower. CAL going around."

TWR: Roger. Stand-by further instruction.

Captain: "(Aircraft) will stall at this rate."

Captain: "No way! No way!"

8:15.25 Engine sounds become louder. Stall warning sound.

Captain: "Don't worry. Don't worry. Don't be upset. Don't be upset."

The Ground Proximity Warning System sounds, "Terrain, Terrain."

F/O: "Power!"

The stall warning sounds and continue until captain yielded : "No Way! No Way!" as the aircraft crashed at 8:15.47. (AW & ST May 2, 1994 p.26)

Appendix C: Airbus Industry A330 Crash Moment Cockpit Voice Record

Time	Captain	Copilot	Flight Engineer
27.40			So we have an engine failure at takeoff to do, yes, so you have to fly 150 knots or more, to engage the autopilot, and then to fail one engine and state three nine seven two is active.
28.03	So the wheels are all good, we have config two	O.K. O.K., euh Elect IDG, one minor fault	
28.10	Yeach, well we know about that but we can just clear that ya'll		
28.16	And.. we have the same speeds as last time		
28.17		O.K. yeah,yeah	
28.19	Flight director is on		
28.23	Spoilers cat three dual	Spoilers. We will take-off then left turn, ninety two hundred seventy, then again, ILS approach fifteen left	
28.42	You take..you take the airplane?	I fly now,yeah	
28.46	What you do now is rotate, let the speed go above V2..and put the autopilot one in	Yeah	
28.55	O.K. As soon as autopilot one is in, throttle one engine back, and I will take the hydraulics off. O.K.?	Yeah O.K.	
29.05	O.K.	Kilo Hotel ready to takeoff as you wish. We keep runway heading and ready for...	
29.16	O.K. runway heading		

29.21	Are you ready behind?		Yeah
29.22	We are ready, here we go, Michel		
29.27	That..careful with the power,initially	Still TOGA right?	
29.30	..cause of the c.g. till we get the ...wait till we see thw airspeed		
29.37	Until we go to full power	O.K.	
29.45	Right,you can go ahead now	TOGA speed reference system(SRS)	
29.49	TOGA SRS		
29.59	100 knots		
30.03	Rotate		
30.08	150, gear up		
30.10	Autopilot in		
30.11	And again..and again		
30.14	Engine failure		
30.17	Pump fault		
30.22	And I...I don't know what's gone		
30.25	Tha..That's not correct. I have control (Speed,speed,speed voice alarm)		
30.27	I have control		
30.31	stall,stall,stall voice alarm		Take care the speed
30.33	Stall alarm		Take care
30.36	pull-up,pull-up alarm		
30.39	continuous stall alarm		
30.42	recording ends		

Source from Aviation Week & Space Technology/August 8, 1994

Appendix D: Aviation Week List of Accidents/Incidents of Man-Machine Interface Problem (Source from Aviation Week & Space Technology/January 30, 1995 p. 59)

1. July/3/1988 A320 Gatewick

FMS programmed for 3 degree flight path, but inadvertently was in V/S mode, almost landed 3 mile short. At least six incidents of V/S flight path confusion have been reported.

2. June/26/1988 A320 Habsheim

Low, slow, idle pass at air show. Ran out of energy and flew into trees. Fatal.

3. June/8/1989 B767 Boston

On A/P ILS approach, aircraft overshot the localizer. Captain switched from approach to heading select mode to regain the localizer, disengaged the A/P, and used the F/D. Since the G/S had not been captured, the F/D was in V/S mode commanding 1,800 fpm. descent instead of staying on G/S. Alert from the ground proximity warning and tower caused a go-around from about 500 feet.

4. Feb/14/1990 A320 Bangalore

Inadvertent altitude acquisition and open descent modes. Fatal crash.

5. Feb/11/1991 A320 Moscow

Pilot versus autopilot dispute caused aircraft to go out of trim, causing five pitch cycles peaking at 70-80 degree nose up and 30 degree nose down. Airspeed varied from nearly 300 kt. to below 30 kt. in roughly 4,000-ft. cycles on a generally climbing path. Roll angles exceeded 100 degree. The aircraft was recovered.

6. Jan/20/1992 A320 Strasbourg

Evidence suggests crew selected 3,300 fpm. on approach instead of 3.3-degree flight path angle. Crew also violated crossing altitudes. Fatal crash.

7. April/26/1994 A300-600 Nagoya

Pilot fighting autopilot caused trim to go to full nose-up position, causing uncontrollable stall when power was applied. A/P was in go-around mode and crew was trying to stay on G/S. Fatal crash.

8. June/21/1994 B757-200 Manchester

After takeoff, at 2,200 ft. the altitude capture mode cut power back while the flight director bars appeared to command a pitchup, and then disappeared. Airspeed dropped toward V2 and the crew pitched down to 10 degree. CAA says "problem considered to be well-known and adequately trained."

9. June/30/1994 A320 Toulouse

Engagement of altitude acquire mode at unexpected point caused steep pitchup and loss of airspeed during engine failure simulation. Airbus chief test pilot distracted by operating systems. Aircraft went out of control and crashed.

10. Sep/24/1994 A310-300 Orly

During approach, flap placed overspeed caused computer mode to switch to flight level change, causing autothrottle to advance to climb power. Trim went to full nose-up for unknown reasons (commanded by the manual system) while elevator was pushed full nose-down. Aircraft pitched uncontrollably into a stall, but was recovered.

Legend: A/P=autopilot F/D=flight director G/S=glideslope V/S=vertical speed

Appendix E: FAA Human Research Team List of Accidents

1. 12/29/1972 Miami L-1011 Eastern

Flightcrew members became immersed in an apparently malfunctioning landing gear. Airplane was in control wheel steering mode. Altitude hold inadvertently disengaged by a light force on the control wheel. Altitude alert aural warning not heard by flightcrew. Fatal crash.

2. 7/31/1973 Boston DC-9 Delta Air Line

Airplane landed short during an approach in fog. Flightcrew was preoccupied with questionable information presented by the flight director. Fatal crash.

3. 2/28/1984 New York DC-10 Scandinavian

Malfunctioning autothrottle system during approach resulted in crossing the runway threshold at 50 knots above reference speed. Runway was wet, touchdown was 4700 feet beyond the threshold of an 8400 foot runway. Airplane overran runway, minor injuries. Complacency and over-reliance on automatic systems cited.

4. 2/19/1985 San Francisco B747SP China Airlines

Loss of power on one engine during autoflight. Autopilot tried to compensate until control limits were reached. Captain disengaged autopilot, airplane went into unusual attitude high speed dive, but was successfully recovered. Autopilot masked approaching onset of loss of control.

5. 6/26/1988 Habsheim A320 Air France

Low, slow fly over at air show. Ran out of energy and flew into trees. Possible overconfidence in the envelope protection features of the A320, Fatal crash.

6. 7/3/1988 Gatwick A320

Programmed for 3 degree flight path, but inadvertently was in vertical speed mode, almost landed 3 miles short.

7. 1/1989 Helsinki A300 KAR Air

While making an ILS approach, the takeoff/go-around lever was inadvertently depressed. In response to the unexpected and sudden nose-up change in the airplane's attitude, the flightcrew immediately reacted by re-trimming.

8. 6/8/1989 B767

On autopilot ILS approach, airplane overshot the localizer. Captain switched from approach to heading select mode to regain the localizer, disengaged the autopilot, and used the flight director. Since the glide slope had not been captured, the flight director was in vertical speed mode commanding an 1,800 fpm rate of descent. Alert from the ground proximity warning and tower resulted in a go-around from about 500 feet.

9. 2/14/1990 Bangalore A320 Indian Airlines
Inappropriate use of open descent mode. Fatal crash.

10. 6/1990 San Diego A320
Pilot mistakenly set vertical speed of 3,000 fpm instead of 3.0 degree flight path angle. Error was caught, but airplane descended well below profile and minimum descent altitude.

11. 2/11/1991 Moscow A310 Interflug
Pilot intervention in auto-pilot coupled go-around resulted in the autopilot commanding nose-up trim while the pilot was applying nose-down elevator. Autopilot disconnected when mode transition to altitude acquire mode- force disconnect not inhibited in this mode as it is in go-around mode. Airplane ended up badly out of trim and went through several extreme pitch oscillations before the flightcrew regained control.

12. 1/20/1992 Strasbourg A320 Air Inter
Evidence suggests flightcrew inadvertently selected 3,300 fpm descent rate on approach instead of 3.3 degree flight path angle. Fatal crash.

13. 9/14/1993 Warsaw A320 Lufthansa
Wet runway, high tailwinds -- After touchdown, the air/ground logic did not indicate the airplane was on the ground, and delayed deployment of ground spoilers and reversers. Airplane overran runway. Two fatalities.

14. 9/13/1993 Tahiti 747-400 Air France
VNAV approach with autothrottle engaged, autopilot disengaged. Upon reaching the published missed approach point, VNAV commanded a go-around and the autothrottle advanced power. After a delay, the flightcrew manually reduced power to idle and held the thrust levers in the idle position. The airplane landed long and fast. Two seconds prior to touchdown the number one engine thrust lever advanced to nearly full forward thrust and remained there until the airplane stopped. Reverse thrust was obtained on the other engines. The spoilers were not deployed -- the automatic system did not operate because the number on thrust lever was not at idle, and the flightcrew did not extend them manually. The flightcrew lost directional control of the airplane as the speed decreased and the airplane went off the right side of the runway.

15. 6/6/1994 Hong Kong A320 Dragonair

After three missed approaches due to lateral oscillations in turbulent conditions, a landing was made and the airplane went off the side of the runway. The flaps locked at 40 degrees deflection (landing position) just before the first go-around due to asymmetry. Asymmetry caused by rigging at the design tolerance combined with gust loads experienced. In accordance with published procedures, flightcrew selected CONF 3 for landing, which extended slats to 22 degrees. With autopilot engaged, lateral control laws correspond to control lever position. Under manual control, control laws correspond to actual flap/slat position. The configuration CONF 3, with flaps locked at 40 degrees, is more susceptible to lateral oscillations with the autopilot engaged. After a similar incident in November, 1993, experienced by Indian Airlines, Airbus issued an Operations Engineering Bulletin to leave the control lever in CONF FULL if the flaps lock in that position.

16. 4/26/1994 Nagoya A300-600 China Airlines

Flightcrew inadvertently activated the go-around switches on the throttle levers during a manually flown approach. This action engaged the autothrottles and put the flight guidance system in go-around mode. Flightcrew disconnected the autothrottles, but excess power caused divergence above the glide slope. Flightcrew attempted to stay on glide slope by commanding nose-down elevator. The autopilot was then engaged, which because it was still in go-around mode, commanded nose-up trim. Flightcrew attempted go-around after "alpha floor" protection was activated, but combination of out-of-trim condition, high engine thrust, and retracting the flaps too far led to a stall. Fatal crash.

17. 6/21/1994 Manchester B 757-200 Britannia

Altitude capture mode activated shortly after takeoff, autothrottles reduced power, flight director commanded pitch-up before disappearing. Airspeed dropped toward V_2 before flightcrew pitched the nose down to recover.

18. 6/30/1994 Toulouse A330 Airbus

Unexpected mode transition to altitude acquire mode during a simulated engine failure resulted in excessive pitch, loss of airspeed, and loss of control. Pitch altitude acquire mode. Fatal crash.

19. 9/24/1994 Paris-Orly A310-300 Tarom

Overshoot of flap placard speed during approach caused a mode transition to flight level change. Autothrottles increased power and trim went full nose-up for unknown reasons (autopilot not engaged). Flightcrew attempted to stay on path by commanding nose-down elevator, but could not counteract effect of stabilizer nose-up trim. Airplane stalled, but was recovered.

20. 10/31/1994 Roselawn ATR-72 American Eagle

In a holding pattern, the airplane was exposed to a complex and severe icing environment, including droplet sizes much larger than those specified in the certification requirements for

the airplane. During a descending turn immediately after the flaps were retracted, the ailerons suddenly deflected in the right-wing down direction, the autopilot disconnected, and the airplane entered an abrupt roll to the right. The flightcrew were unable to correct this roll before the airplane impacted the ground.

21. 3/31/1994 Bucharest A310-300 Tarom

Shortly after takeoff in poor visibility and heavy snow, with autothrottles engaged, climb thrust was selected. The right engine throttle jammed and remained at takeoff thrust, while the left engine throttle slowly reduced to idle. The increasing thrust asymmetry resulted in an increasing left bank angle, which eventually reached about 170 degrees. The airplane lost altitude and impacted the ground at an 80-degree angle. Only small rudder and elevator deflections were made until seconds before impact, when the left throttle was brought back to idle to remove the thrust asymmetry. Fatal crash.

22. 11/12/1995 Bradley MD-80 American Airlines

On a VOR-DME approach, the airplane descended below the minimum descent altitude, clipped some tree, and landed short of the runway. Contributing to this incident was a loss of situation awareness and terrain awareness by the flightcrew, lack of vertical guidance for the approach, and insufficient communication and coordination by the flightcrew.

23. 12/20/1995 Cali B757-200 American Airlines

Unexpectedly cleared for a direct approach to Cali, the flightcrew apparently lost situation awareness and crashed into a mountain north of the city. On approach, the flightcrew were requested to report over Tulua VOR. By the time this waypoint was input into the flight management computer, the airplane had already flown past it; the autopilot started a turn back to it. The flightcrew intervened, but the course changes put them on a collision course with a mountain. Although the ground proximity warning system alerted the flightcrew, and the flightcrew responded, they neglected to retract the speedbrakes and were unable to avoid hitting the mountain. Fatal crash.

24. 2/6/1996 Puerto Plata 757-200 Birgenair

After taking off from Puerto Plata, the flightcrew lost control of the airplane during climb and crashed into the ocean off the coast of the Dominican Republic. Problems with the captain's airspeed indication were encountered during the takeoff roll, and the takeoff and initial climb out were conducted using airspeed call outs by the first officer. Continued erroneous airspeed indications, possibly due to a blocked pitot tube, required in an overspeed warning during climb. Shortly thereafter the stickshaker activated. The conflicting warnings (overspeed and stall) apparently confused the flightcrew. The airplane entered a stall from which it did not recover. Fatal crash.

Appendix F: Embry-Riddle Survey of Different Opinions on FMS Increasing or Decreasing Workload:

Comments increase workload	Comments decrease workload	Others
Automation has increased workload. If I haven't flown it in several weeks as well as in rusted situations, i.e., changed runway at last moment, or late issuance of a clearance/request. (G-IV-F/O)	Workload is decrease markedly during flight if the system is programmed properly and accurately in the first place. (BE-2000/400-Capt.)	Work saving, but seductive. Too much head down in high density areas. (G-IV-F/O)
It requires an above normal amount of heads down time especially takeoff/departure and approach/landings. ATC contributes to this problem with numerous changes. (CE-650, LR-35-Capt.)	Workload has greatly decreased from non-automated aircraft when everything goes as pre-programmed (DA-20, DA-50 -Capt.)	It is great equipment and can contribute to safer flights. It does require considerable training and peaks of high workload. Crews must guard against complacency and remain in the loop at all times. (CL 600, L329-C/P)
Workload is increased during approach phase with ATC changes to the arrival routing or the approach. (Bae-125-800, G-III-Capt.)	They reduce the workload greatly - makes the flights much smoother. (G-III, CL-601-Capt.)	It eliminates some of the work involved with the old systems, but it also creates problems of its own, such as too much heads down in critical situations if you don't have the discipline to have pilot not flying do the work. (DA-50/900-Capt.)
Automation has increased workload on approaches, especially when runway changes occur. It is not fully used to its capabilities in high traffic areas i.e. NYC, Chicago, LAX, etc. (CE-650, G-IV-Capt.)	The information they provide significantly reduces pilot workload throughout all phases of flight, and enhances cockpit resource management. The real time data the FMS provides, such as fuel flow, position, time, distance, wind speed and direction, aircraft weights, and much more can only	Feel great to be flying state of the art equipment, but when inactive, as far as flying the aircraft, takes longer to get up to speed on the FMS and EICAS systems than older, more comfortable system. VNAV is unable to be used because of ATC constraints (idle descents are unacceptable).

	enhance the safety of flight, by reducing the workload on the flight crew. (CL 601-3A, CE 560 - Capt.)	(G-IV, DA-200, BE-200-Capt.)
Increased Workload in terminal area and last minute ATC changes. (DS-50, N-265, BAe-800-Capt.)	Once you become proficient it greatly reduces the workload and makes for a much safer operation. (G-IV/III, MD-80 - Capt.)	I enjoy it but I don't trust it. (CE-650-Capt.)
Preflight checks and procedures are much more involved, and have not noticed any real decrease in other modes of flight. The largest increase is in short drop and go situation where FMS needs a re-program. (G-IV-Capt.)	Although preflight workload and approach workloads are relatively high - the benefits realized by reduced ultimate workload during takeoff or landing emergencies is a real benefit. (G-IV - Capt.)	I have great praise for this technology. It gives you a lot of useful information, but it also tends to keep heads down more inside the cockpit. (Bae 125-800, DA 50, N265-Capt.)
Increased in some phases - preflight programming versus filling out old card manually because programming requires entering more parameters than old card. (G-IV, CE-550/560-Capt.)	The new equipment is much easier to fly and under high workload keeps you informed of the info you need in one/two convenient places. (BE-40/300 - Capt.)	I am very much in favor of the highly automated aircraft. The only real problem in flying them is a need to fly them fairly often maintain currency. I only average one flight a month, and it is difficult to stay current with all of the FMS features under those circumstances. (G-IV, BE-400A-Capt.)
Obviously workload on the ground before flight due to more tests and set-up of departure information. (CE-560/550-Capt.)	Assuming you get the requested route you file - your workload is significantly reduced from takeoff to landing. Otherwise, you need two FMS units, so the first officer can program as changes occur - then transfer the new information to the captain and flight guidance computer. (DA-900-Capt.)	The automated cockpit is great. However, there are too many gadgets, bells, and whistles for the human brain to take in. Sometimes trying to utilize everything means missing an important function somewhere else. (CE-550-Capt.)

It unfortunately seems to increase the workload when it is already highest - around the airport during an approach. (DA 900/50 -C/P)	Decreased workload in power setting, calculating descent gradient to make a fix at altitude, VNAV is great. (G-IV, CE-550/560-Capt.)	Great-but you must stay current and fly frequently to keep proficient. (CL-601-Capt.)
Greatly increased workload on descent, approach, and landing, mostly because the automation fails, or doesn't do what you want it to do. You then have to figure out why, then correct error if possible. (G-IV-Capt.)	Has made enroute calculations of ETA and fuel remaining easier. (G-III, Bae-800 - F/O, CE-560-Capt.)	It is great step forward, but requires proper training and some experience with the system. (G-IV, BE-400A-Capt.)

Appendix G: FAA Requirements to be an Airline Pilot

(61.153) Airplane rating: Aeronautical knowledge

An applicant for an airline transport pilot certificate must, after meeting the requirements of 61.151 and 61.155, pass a written test on-

- (a) The sections of this part relating to airline transport pilots and part 121, subpart C of part 65, and 91.1, 91.3, 91.5, 91.11, 19.13, 91.103, 91.105, 91.189, 91.193, 91.703, and subpart B of part 91, and so much of part 21 and 25 as relate to the operations of air carrier aircraft.
- (b) The fundamentals of air navigation and use of formulas, instruments, and other navigational aids, both in aircraft and on the ground, that are necessary for navigation aircraft by instruments.
- (c) The general system of weather collection and dissemination.
- (d) Weather maps, weather forecasting, and weather sequence abbreviations, symbols, and nomenclature.
- (e) Elementary meteorology, including knowledge of cyclones as associated with fronts.
- (f) Cloud forms.
- (g) National Weather Service Federal Meteorological Handbook.
- (h) Weather conditions.
- (i) Air navigation facilities used on airways.
- (j) Weather information and meteorological data reports.
- (k) The influence of terrain on meteorological conditions and developments, and their relation to air carrier flight operations.
- (l) Radio communication procedures.
- (m) Basic principles of loading and weight distribution and their effect on flight characteristics.

(61.155) Airplane rating: Aeronautical experience

(a) An application for an airline transport pilot certification must hold a commercial pilot certificate.

(b)

1. At least 250 hours of flight time as a pilot in command of an airplane. At least 100 hours of which were cross-country time and 25 hours of which were night flight time.

2. At least 1,500 hours of flight time as a pilot including:

(i) 500 hours of cross-country flight time.

(ii) 100 hours of night time.

(iii) 75 hours of actual or simulated instrument time, at least 50 hours of which were in actual flight.

(Flight time used to meet the requirements of paragraph (b) 1 may also be used to meet the

(b) 2.

(61.157) Airplane rating: Aeronautical skill

(a) An applicant for an airline transport pilot certificate must pass a practical test that includes: (1) Preflight, (2) Takeoffs (3) Instrument Procedures (4) Inflight Maneuvers (5) Landings and Approaches to Landings (6) Normal and Abnormal Procedures (7) Emergency Procedures. (The detail see Appendix D)

According to the regulations list above, it is still addressed heavily on the flying skills and basic aeronautic knowledge. Then it is important for us to further evaluate the training requirements that an airliner need to do to train their pilots. The FAR listed its requirements as follow:

Training (135.321)

There are six categories of training need to be defined :

1. Initial training: The training required for crewmembers who have not qualified and served in the same capacity on an aircraft.
2. Transition training: The training required for crewmembers who have qualified and served in the same capacity on another aircraft.
3. Upgrade training: The training required for crewmembers who have qualified and served as second in command on a particular aircraft type, before they serve as pilot in command on that aircraft.
4. Differences training: The training required for crewmembers who have qualified and served on a particular type aircraft, when the Administrator finds differences training is necessary before a crewmember serves in the same capacity on a particular variation of that aircraft.
5. Recurrent training: The training required for crewmembers to remain adequately trained and currently proficient for each aircraft, crewmember position, and type of operation in which the crewmember serves.
6. In flight: The maneuvers, procedures, or functions that must be conducted in the aircraft.

(135.331) Crewmember emergency training (pilot areas)

1. Instruction in emergency assignments and procedures, including coordination among crewmembers.
2. Individual instruction in the location, function, and operation of emergency equipment.
3. Instruction in the handling of emergency situations.
4. Review of the certificate holder's previous aircraft accidents and incidents involving actual emergency situations.

(61.151) Eligibility Requirements

- (a) Be at least 23 years of age.

- (b) Be of good moral character.
- (c) Be able to read, write, and understand the English language and speak it without accent or impediment of speech that would interfere with two-way radio conversation.
- (d) Be a high school graduate.
- (e) Have a first-class medical certificate within the 6 months before the date he applies.

Ground Training

(135.345) Pilots: Initial, transition, and upgrade ground training

This training must include at least:

1. The certificate holder's flight locating procedures.
2. Principles and methods for determining weight and balance, and runway limitations for takeoff and landing.
3. Enough meteorology to ensure a practical knowledge of weather phenomena, including the principles of frontal systems, icing, fog, thunderstorms, windshear and if appropriate, high altitude weather situations.
4. Air traffic control systems, procedures, and phraseology.
5. Navigation and the use of navigational aids, including instrument approach procedures.
6. Normal and emergency communication procedures.
7. Visual cues before and during descent below DH or MDA.
8. Other instructions necessary to ensure the pilot's competence.

The Flight Training

(135.347) Pilots: Initial, transition, upgrade, and differences flight training

- (a) The training for pilots must include flight and practice in each of the maneuvers and procedures in the approved training program curriculum.
- (b) The maneuvers and procedures required by paragraph (a) of this section must be performed in flight, except to the extent that certain maneuvers and procedures may be performed in an aircraft simulator, or an appropriate training device.
- (c) If the certificate holder's approved training program includes a course of training using an aircraft simulator or other training device, each pilot must successfully complete--
 - (1) Training and practice in the simulator or training device in at least the maneuvers and procedures in this subpart that are capable of being performed in the aircraft simulator or training device.
 - (2) A flight check in the aircraft or a check in the simulator or training device to the level of proficiency of a pilot in command or second in command, as applicable, in at least the maneuvers and procedures that are capable of being performed in an aircraft simulator or training device.

Appendix H: The Examples of Alternative Basic Training Methods

Lufthansa Airline.

In the mid 1950s, the Lufthansa, West Germany's flag airline, started a so called ab initio training program. After initial ground school classes in Bremen, students transferred to the company's contract facility at Goodyear, Arizona (near Phoenix) for 105 hours in single-engine aircraft and 170 hours of class work. Then students return to Bremen for simulator training and more ground school, then return to Arizona to continue flight training in twin-engine aircraft. The ab initio (students self-improvement from the beginning) training totals 250 hours of flight training, plus 210 hours of ground school and simulator training to be completed before a pilot can be a qualified Lufthansa first officer for domestic B-737s (Glines:1990b,18).

China Airline.

Taiwan's China Airline send its student pilots to University of North Dakota (UND) for Spectrum and Advanced Spectrum pilot training. The program consists of a 15-month ab initio Spectrum course. Most of the initial training is in single-engine Piper PA-28R series aircraft. Twin-engine Piper PA-44 Seminoles are used for multi-engine instruction. The graduated students have 550 hour flight time with a U.S. commercial license with instrument and multi-engine ratings. Then they spend two months in Taiwan to get a commercial license and return to UND for further training. The key point of this training is to refine the piloting capabilities and enhance decision-making skills. The advanced Spectrum program consists of three phases. Phase 1 uses King Airs (Beechcraft C90A) for turbine transition training and requires 100 hours of flight/observer time and 31 hour of simulator training. Phase 2 requires 160 hours for both flight and crew time as a first officer in Beech-1900. Great Lakes Aviation Inc. provides scheduled revenue passenger service for those students. Phase 3 provides recurrence training every 90 days and line-oriented flight training (Phillips,1992a:67).

British Aerospace Flying College.

British Aerospace's Flying College offers a 16 month course for possible employment with British Airlines. Trainees attend the International Airline Training Center (IATC) in Lakeland, Florida., for the first phase of their flight training (Swissair and Alitalia Airlines have similar programs, and Taiwan's China Airlines has its airline's ab initio class at the University of North Dakota) (Glines,1990b).

Florida Institute of Technology.

The Florida Institute of Technology (FIT) has a collaborative program with United Airlines to provide possible flight officer positions. After graduation they are then screened at

United's Denver training facility and if they satisfy requirements, they return to FIT to become full-time paid flight instructors for one year (Glines,1990b).

Embry-Riddle Aeronautical University.

The famous Embry-Riddle Aeronautical University has a standardized entry-level airline pilot training program under FAA auspices. Completing such a program would be "post ab initio" and qualify anyone seeking an airline piloting job. They have six criteria (Glines,1990b):

1. Candidates would have to meet FAA-developed minimum criteria such as graduation from an approved flight school, bachelor's degree or equivalent (See FAR part 61.151).
2. Candidates would be selected based on psychological, medical, personality, and other types of testing.
3. The training would be a mix of simulators, turboprop aircraft, full mission/crew-oriented training, and emphasis on cockpit resource management.
4. This would be a joint venture with the participation of FAA, major and regional airlines, flight schools, aircraft and simulator manufacturers.
5. Professional ground school instructors, designated FAA inspectors, and industry-designated inspectors would staff each training facility.
6. When the program is completed, students are qualified to be hired by regional or major airlines.

Comair Airline.

Cincinnati-based Comair Airlines has formed the Comair Aviation Academy at Sanford, Fla. A high school diploma and second class medical ratings plus an instrument rating are required and training would be at students' own expense. After graduation, an interview with Comair would possibly provide them the chance to transition into the right seat after another 16 months' training (Glines,1990b).

Appendix I : The Examples of Operating Skill-Based FMS Training Philosophies

The United Airlines. That company provides a consistent, mission-oriented approach to cope with the highly automated aircraft which integrates crew resource management and measures pilot performance throughout the learning cycle. UA conducts an Advanced Qualification Program (AQP) (details in next page). It de-emphasizes the need for in-depth knowledge of basic aircraft systems operation (William,1995:50). In their point of view, as S. William Reichert, United's manager of fleet operations for A320 says : "Pilots are getting younger and are more computer literate, so we have moved away as much about how the aircraft works", "We now teaching system operation, more on interfacing with the aircraft through the FMS, more mission-oriented, not as maneuver-oriented (the term "mission oriented" came from the common complaints directed at traditional aircrew training and checking programs that they are maneuver-oriented, frequently including maneuvers that are not necessary. (Bob:1990) as we used to be".

The Airbus industry. to fit the transition training needs, the Airbus industry designed a course to eliminate pilots' concerns about its automation feature. They realized that not everyone who takes that course are raised on computers and video games. To the older pilots, computers can be threatening. So, the first part of A320 training was like that for any other aircraft. After that, they were trained to operate the A320 using specific aircraft configurations chosen for each flight segment. Finally, they learned the procedures for abnormal situations and emergencies. Some trainees said "The A320 is not really a difficult aircraft, but it is a totally different aircraft, and the pilots therefore have to break away from their previous flying experience" (Jeffrey,1992:62).

Air Canada. Air Canada's pilots use computer-based instruction consoles which all have FMS control display so they can practice making entries. Air Canada and TWA have fixed simulators with FMS installed so pilots can practice loading the computers before entering the full motion simulator training (David,1992b:52).

The Advanced Qualification Programs (AQP)

The FAA Special Federal Aviation Regulation 58, signed into law on September 26, 1990. This new rule permits air carriers, following a rigorous instructional system design process, to develop their own unique pilot qualification programs, independent of traditional regulations and artificial constraints, but meeting the industry recognized requirement for operational crew oriented training. It can be described as:

- mission oriented
- proficiency based
- analytically developed
- empirically validated

To be approved, an AQP program must include:

- Cockpit Resource Management training and evaluation
- Line Operational Simulations (LOS) for both Line Oriented Flight Training (LOFT) and Line Operational Evaluations (LOE), as defined in Advisory Circular 120-35B
- Specialized training for instructors and evaluators.

(Source from Bob Smith - Implementation of New Technology - A United Airline's Perspective, published in 1990 by Society of Automotive Engineers, Inc.pp-16)

Appendix J: Open-Ended Questionnaire and Comments from Pilots for Automation

Open-ended question 1. Briefly describe an operational problem - that you personally know of - involving the automated features of your aircraft that could have had a negative safety consequence. How could the error have been avoided?

Table 1. Frequency of categorized responses for open-ended question 1 (n=339)

Response Category	Frequency
Heads-Down/Inside Cockpit	47
Data Input Error	38
Altitude Problems "Busts"	25
Design/Interface	22
Training	20
Crew Communication	19
Equipment Failure	17
Check Data Entered	15
Autothrottle Incidents	14
System Software	13
Air Traffic Control	12
System Induced	12

Table 1 shows the most frequent response was **the amount of time spent heads-down in the cockpit**. The second most frequent response was **the number of data input or programming errors**.

The sample of comments

1. During initial automated operations, individuals spend excessive time in head-down situation. Become more heads-up as experienced is gained. (BAe 800, SK 76A-Capt.)
2. When systems are new to a crew, too much "heads down" in the cockpit: spend more time in cockpit using equipment in hangar or on a mock flight. If system malfunction soon after takeoff, too much "head down" in cockpit: leave it alone until out of FL 180 or later and then reinitialize or reprogram. (Bae-800, CE-650-Capt.)
3. A new system or a pilot just introduced to highly automated cockpit can have too much

heads down time, therefore, decreasing safety considerably. (DA-900, DA-50-Capt.)

4. ".....with all of the functions now possible for use during an arrival, I find many pilots spending too much time in the cockpit pushing buttons when they should be watching for traffic." (G-IV, BAe-800--Capt.)

5. "During transition into the automated cockpit, there was an inordinate amount of 'heads down ' time which left me a bit uncomfortable at first. Once the crew got user friendly with the systems, this uneasiness vanished." (DA-50, BE-400A--Capt; G-IV-F/O)

6. "Pilots flying new equipment tend to spend too much time inside cockpit playing with 'new gadgets' and not looking for traffic during critical times of flight. Basic observation during flight training and flight instructing." (CE-550/650-Capt., C/A, Inst.)

Open-Ended Question 2. Were there any instances in which the automated features "saved the day" or had a positive safety consequence?

Table 2. Frequency of categorized responses for open-ended question 2 (n=248)

Response Category	Frequency
Multi Function Display (MFD)	49
Auto Commands (airspeed, altitude, hold)	33
Increases Situational Awareness	26
Reduces Workload	17
Traffic Collision Avoidance System (TCAS)	15
Improves Safety	14
Simplifies International Flying	14
Heads-up Comments	8
Vertical Navigation (VNAV)	4
Extend Runway Centerline	3

The great majority of responses indicated that the MFD greatly assists **normal piloting duties**. Pilots also reported that the MFD provides important information quickly during critical times, thus allowing for better situational awareness. The second most frequent response was the convenience of autocommands (e.g., airspeed, altitude, holding). Pilots appear to be very pleased with these automated features which apparently reduce their inflight workload, allowing more time for outside scanning. Pilots indicated that these

capabilities are very helpful, from autohold in heavy weather to autocall of emergency procedures on the checklist.

Sample of Comments

1. "...map display on the MFD greatly helps you in keeping track visually of your position in relation to airport and what position you are during instrument approach." (DA-50/900, CE-650--Capt.)
2. "FMS Nav features are extremely helpful when navigation outside of U.S. Also the ground track nav. display gives an excellent picture of aircraft position." (G-II/IV--Capt.)
3. Autothrottles continue to 'save the day' and have positive safety consequences. (G-IV, CE-550/560--Capt.)
4. Autothrottle go around with missed approach programmed in the FMS + heavy weather and winds 35-40 mph. It was very comforting that the aircraft knew what to do when we had a hard time just seeing a blurred instrument panel. (G-IV, CL-601--Capt.)
5. The altitude hold at the pre-selected altitude selection is out standing. (G-IV--Capt.)
6. "...and with performance computer and throttle - less monitoring of power and speed means more for traffic." (G-IV--Capt.)
7. "All of the alert features both aural and /or visual such as altitude, terrain, and program and capture modes are very positive safety features." (DA-900--C/P)

Open-Ended Question 3. "What operational features should be added to improve safety and/or reduce workload"

Table 3. Frequency of categorized responses for open-ended question 3 (n=291)

Response Category	Frequency
Simplify Software	43
Standardize Keypads and Location	27
Heads-up display	22
Traffic/Collision Avoidance system	16
Training	15
Put controls higher/more forward	14
Better/Expanded Databases	11
Standardization	11
Minimize display clutter	9
Other (AOA, back-to-basic-button)	9

Aural Warnings	5
Keep Past Waypoints Alive	4
Terrain/Obstacle Information Displayed	4
Airspeed Trend/Thrust Vector	3
Clear View of EFIS	3

Simplify Software (Sample of Comments)

“..make the systems user friendly, easier to learn, use, and understand. Less typing equals less chance for mistakes. It is easy to get lost with data input and tends to be a more difficult system to remember. All in all, it is not user friendly.” (CE-650-Capt.)

“All automated systems could be made better by constantly improving software to lessen keystrokes required to effect a specific function i.e., to built a RNAV approach, or SID/STAR.” (BE-2000/400-Capt.)

Standardize Keypads (Sample of Comments)

“..several pilots including myself wish that they would employ a standard typewriter keyboard format...” (DA-50-Capt.)

“Keyboards have to be well-lighted at night and lebeled with larger letters for the various functions.” (DA-50-Capt)

**Open-Ended Question 4B. What effect has automation had on your workload?
Where has it increased workload? Where has it decreased workload?**

Table 4B. Frequency of categorized responses for open-ended question 3 (n=129)

Increased Workload responses	Frequency
Preflight Planning	56
ATC Changes	19
Descent/Approach	15
Initial Learning	7
Terminal Area	7
Takeoff/Departure	6
Decreased Workload Responses	Frequency
Enroute	39

General Decrease	31
Once Experienced with systems	13
Automatic computations	13
Preflight and Programming	10
Descent/Approach	8
Takeoff/Departure	8
SIDs/STARs/Flight Plans Easily	4

Table 4 shows the frequency of responses by workload category for open-ended question 4. The comments for this question were divided into two categories: increased workload and decreased workload. It appears that the pilots' perceptions of workload are equally divided, where 110 comments reported some increase in workload, and 126 comments indicated a workload decrease.

Most comments were relatively consistent: pilots reported that preflight checks, procedures, and programming the FMS are more involved as compared to the procedures in non-automated aircraft.

For those reporting a decrease in workload, enroute was the most frequent response. Pilots indicated that the amount of information available and the ease of accessing that information has vastly improved.

Sample of Comments

1. "Preflight checks and procedures are much more involved, and have not noticed any real decrease in other modes of flight. The largest increase is in short drop and go situation where FMS needs a re-program." (G-IV--Capt.)
2. "My preflight and system programming duties have increased dramatically." (G-IV, CE-650/560--F/O)
3. "Increases workload on the ground before flight due to more tests and set-up of departure information." (CE-560/550--Capt.)
4. "Obviously workload has increased in the preflight stages whether we program a flight plan to computer disk in the office or work n the FMS in the aircraft." (DA-900, CL-601--F/O)
5. "It unfortunately seems to increase the workload when it is already highest - around the airport during an approach." (DA 900/50--C/P)
6. "Greatly increased workload during approach and landing, mostly because the

automation fails, or doesn't do what you want it to do. You then have to figure out why, then correct error if possible. Computer is slow, and you are trying to fly the approach." (G-IV--Capt.)

7. "It decreased workload on most flight where most factors are known, such as standard routings and arrivals as well as predictable passengers requests and schedules." (G-IV--F/O)

8. "Decreased workload in power setting, calculating descent gradient to make a fix at altitude." (G-IV, CE-550/560--Capt.)

9. "With experience, the workload has gone down to where it is easier to fly than older aircraft." (G-IV--Capt.)

10. "Initially the workload doubled. But, as we learned the system more thoroughly, and became more trusting with the system and its accuracy, the workloads have actually decreased." (CE-650/550--C/P)

11. "Initial learning phase is significantly increased. After about 20-30 hours of hands on experience workload decreases." (DA-50, CL-601--Capt.; G-IV-F/O)

Open-Ended Questions 4. Briefly describe your initial training for the automated aircraft you fly. What were the best parts? What were the worst parts?

Table 4. Frequency of categorized responses for open-ended question 4 (n=132)

"Best Part" Responses	Frequency
Training Device/Simulator	11
"Worst Part" Response	Frequency
No Formal Training	23
Training Materials/Support Inadequate	20
Poor Initial Training	6
Too Much Too Soon	6
Not Enough Flying the Aircraft/Too Much Emphasis on FMS	4
Not Enough Time on the FMS	2

Several pilots critique the quality of their initial training. Because EFIS/FMS systems are relatively new in corporate aviation, most training organizations (e.g., Flight Safety, SimuFlite) had limited experience with automated equipment. From the pilots' perspective, as well as that of the training organizations, it is unfortunate that these aircraft were

manufactured and delivered before any structured curriculum and/or training support could be developed. The majority of pilots giving "worst part" responses indicated that they did not receive any formal training. Most indicated that their training consisted of on-the-job, learn-as-you-go scenarios. Many others reported that they just read the manual and received instruction tips in the hangar.

Sample of Comments

1. "BEST-FMS training device. Excellent simulator (Phase II) entire check ride accomplished in simulator." (CE-650, G-IV--Capt.)
2. "EFIS/FMS simulators best parts." (G-1159A, CE-650--Capt; CE-560--Capt; BE-30--F/O)
3. "Simulator training best flight training." (G-IV--Capt.)
4. "I did not really have any initial training other than reading the manual myself and the chief pilot giving me hands on pointers on a trip." (CL-600/601-3A, G-1159--Capt.)
5. "My initial training involved myself on the ground with a manual and sitting in a powered up electronic system. Then I went on a trip and was given instruction on the way. This is very typical. Some pilots don't even have the desire to sit in the aircraft on the first trip." (CE-550/650--Capt.)
6. "There was none. We learned on the job and it was difficult. There were many mistakes and we were lucky not to get violated. Not recommended." (G-III--Capt.)
7. "Although my initial training was for a First Officer position, no training for EFIS/FMS was available." (CE-650/550--Capt.)
8. "No initial training was received - this is my greatest concern as we keep advancing in automation. Training institutions and manufactures must get together and offer initial as well as recurrent training to pilots who will be flying these systems. Technology is moving very fast; let's be sure we are on the same page." (G-III, CE-605--Capt.)
9. "I received training on our FMS system from other crew members in our flight department. There was no formal training on our type rating as the system installed varies with the operator." (BE-200/400--Capt.)
10. "Worst - poor training materials (1989); improper lighting in simulator; improper emphasis in simulator; infuriating sensitivity of barometer setting procedures; poor design of some indicators (DME)." (G-IV, CE-650--Capt.)
11. "Poor/brief - trained on older equipment that differed substantially from advanced

version in our new aircraft. Group of 9 pilots 'self taught' and 'group helped' on training flights using manual supplied. Like computer applications - the best way to learn is to get in there and play around - hopefully on the ground." (CL-601--Capt.)

Open-Ended Question 5. Describe any problems that you had in an automated aircraft during: (a) your initial operating experience, and (b) your subsequent operating experience.

Table 5. Frequency of categorized responses for open-ended question 5 (n=122)

Initial Operating Experience	Frequency
General Confusion	9
Getting Use to EFIS	7
Calling up Correct Page/Display	6
Heads-Down/Inside Cockpit	5
Push Wrong Buttons/Slow Entering Data	5
Too Much Going On	5
Uncertainty in Programming	5
Other	2

The majority of the responses indicate that there is a large learning curve with these automated systems. It appears that many of the initial experience problems reported are due to a lack of familiarization with these systems. When pilots acquire enough experience, these perceived problems seem to disappear or become less severe.

Sample of Comments

1. "No major problems. Just lots of head scratching until everyone learned ins and outs of system. Everyone tried all the different modes of display etc. and finally settled on the one they liked." (DA-50, HS 125-800- C/P)
2. "Autothrottle creates considerable confusion on takeoff, initial climbout and on go-around." (G-IV--Capt.)
3. "Getting used to the EFIS display was the hardest. I can not imaging going back to a 'non-glass' cockpit now, however." (CL-601-3A, P-3C--Capt.)
4. "Main problem was calling up the correct display on the screen for the function that I wanted to use or modify in a flight plan." (G-III-Capt.; CL-601-F/O)
- 5 "Initially it is extremely difficult to figure out exactly how to program or pull up the data

you want, i.e., how to get the correct page up to program the system.” (G-IV-Capt.)

Open-Ended Question 6. What impact, if any, has automation had on your recurrence training?

Table 6. Frequency of categorized responses for open-ended question 6 (n=129)

Response Category	Frequency
Very Little/Virtually None	46
Negative Impact	14
Train in a Simulator Unlike Aircraft Flown	13
Others	12
Increases the Need for Training	6
Positive Impact	6
Emphasized the Need for New Crew Coordination Training	5
Need to Keep up with Software Changes	5
Made it More Difficult	4
Notice Some Degrade in Flying Skills	4

Although several pilots reported that automation has had virtually no impact on their recurrent training, others indicated that it has a negative impact. The major concern expressed was that most simulators are not equipped like the aircraft in which pilots fly.

Sample of Comments

1. “I think that some deterioration in effectively may be occurring due to allocating too much time to FMS/automation at expense of not accomplishing most/all of emergency procedures on the checklist. This is a mistake. I feel that the main priority of recurrence training is being missed.” (G-IV, CE-650--Capt.)
2. “Today, recurrent ground school and simulator training with Flight Safety dose not include any work with electronics. This must change.” (CE-550--Capt.)

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Vita

Major Kuo Kuang Liu is from Taiwan, Republic of China. He graduated from the Chinese Air Force Academy in 1985 with a Bachelor of Science degree and expertise in fighter pilot assignment. After serving in an F-5 fighter squadron for eight years, he received his first overseas training at the Naval Post Graduate School for Aviation Safety Officer training in Monterey, California. He then devoted all his efforts to aviation safety training. Major Liu entered the Air Force Institute of Technology in June 1995. He will serve for Chinese Air Force Headquarters after graduation.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 074-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1997	3. REPORT TYPE AND DATES COVERED Master's Thesis		
4. TITLE AND SUBTITLE THE HIGHLY-AUTOMATED AIRPLANE: IT'S IMPACT ON AVIATION SAFETY AND AN ANALYSIS OF TRAINING PHILOSOPHY		5. FUNDING NUMBERS		
6. AUTHOR(S) Kuo Kuang Liu, Major, ROCAF				
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology 2750 P Street WPAFB OH 45433-7765		8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/GSM/LAC/97J-1		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSORING / MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (<i>Maximum 200 Words</i>) As technologies in the engineering design progress so quickly in airplane automation, training philosophies toward the "glass cockpit" may need to be re-evaluated. The findings of this thesis suggest that in the highly-automated cockpit era, basic flying skill training, operating skill-based training, and functional knowledge-based FMS training are all important during the training phase due to the unique features of the highly-automated cockpit.				
14. SUBJECT TERMS Highly-Automated Airplane, Flight Management Systems, Flying Skill-Based Training, Operating Skill-Based FMS Training, Functional Knowledge-Based FMS Training.			15. NUMBER OF PAGES 98	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	